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ABSTRACT

This proceedings document contains approximately 250 papers and posters presented at a conference on the advancement of rehabilitation and assistive technology. Individual sessions focused on the following topics: quantitative functional evaluation, upper limb and therapeutic stimulation, human-computer interface developments, information networking, gerontology, clinical seating and mobility issues, robotics and advanced technology, systems development and speech synthesis in augmentative and alternative communication, sensory aids, clinical applications of adapted computer use, approaches to assistive technology service delivery, positioning and mobility, simulation for lower limb function, rural rehabilitation, job accommodations, clinical issues and research in augmentative and alternative communication, research in powered mobility design and control, assistive technology devices and evaluations, personal transportation, special education, technology transfer, and clinical concepts in powered mobility. Additional brief papers on similar topics were presented at poster sessions and are reprinted. Also provided are the text of papers presented at an international symposium on robotic manipulators in rehabilitation practice, presentations of the Wheelchair Standards Committee, and winning papers of the Easter Seal student design competition. Proceedings papers typically include an abstract, text, illustrations or graphs, address of the principal investigator, and references. (DB)

# PROCEEDINGS

# TOWERING ACHIEVEMENTS





## TECHNOLOGY FOR CONSUMERS

## RESNA INTERNATIONAL '92

JUNE 6-11, 1992

SHERATON CENTRE
HOTEL AND TOWERS

TORONTO, ONTARIO, CANADA

# PROCEEDINGS
# of the
# RESNA International '92
# Conference

## Technology
## for
## Consumers

June 6-11, 1992

Sheraton Centre Hotel and Towers
Toronto, Ontario, Canada

Jessica J. Presperin, OTR/L, MBA
Editor

Stephen Naumann, PhD
Morris Milner, PhD CCE
Conference Co-Chairs

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# Foreword

RESNA is an interdisciplinary association for the advancement of rehabilitation and assistive technology. Its members includes consumers, engineers, scientists, physicians, orthotists, prosthetists, therapists, technicians, special education, vocational rehabilitation councilors, manufacturers, suppliers, administrators and others concerned with the development and provision of assistive technology. The RESNA International '92 Conference and these proceedings are a reflection of our continuing commitment to provide a variety of forums through which individuals meet and exchange current information in the field.

This year's theme, "Technology for Consumers," is promoting the application of technology in employment, education, and independent living of people with disabilities. After twelve years, the conference has returned to Toronto, the place of origin of the Passing of The Hat ceremony and the first international conference. Once again our meeting in Canada has brought together a large number of professionals, products and service ideas from around the world.

Towering Achievements are consistently needed for the consumers that all professionals in the field strive to serve. These proceedings are comprised of 228 papers submitted by authors representing over a dozen countries. They reflect the progress in the past year of numerous facets of rehabilitation and assistive technology. As with previous proceedings they provide a rich source of valuable and current information about developments in the field. This year's proceedings have been further enriched by increased international participation.

As in the past, our conference creates an opportunity to revitalize our commitment, share ideas, renew friendships, and add faces to familiar names. On behalf of the organizers of this year's conference and the RESNA Board of Directors we extend a warm welcome to Toronto. Work, enjoy, return home safely, and plan on being with us next June 25-30 in Las Vegas!

Douglas A. Hobson, Ph.D.
President

Stephen Naumann, Ph.D.
Morris (Mickey) Milner, Ph.D.
RESNA International '92 Conference Co-Chairs

# Preface

Welcome to RESNA International '92 "Technology for Consumers." We have come together from around the world to share information concerning assistive technology for empowering people with disabilities. The focus of consumer involvement will be apparent throughout this conference.

The Meetings Committee, chaired by Don McNeal, developed some new ideas based on suggestions from the membership and Board of Directors, while keeping with traditions that have become a valued part of the RESNA Conference. Don, aware of the needs to change the conference program brochure for easier reading, designed a larger layout and user-friendly day-at-a-glance insert.

The SIGs and other groups were provided with time and space to creatively come up with their own format for meeting their members' needs. Along with time allotted for platform and poster presentations, a record number of special sessions were requested. These special session vary from lecture, round-table discussions, show-and-tell, lunches, issue-based dialogues, and debates, to other forums for allowing members to meet for information exchange, see old friends, and make new ones. Co-sponsored SIG activities have also been added to this year's agenda. Many thanks to all of you who were involved in the efforts to bring these ideas to fruition.

The Quality Assurance Committee is beginning to take steps for defining and credentialling professionals in assistive technology. Conference participants will have the opportunity to partake in this endeavor and are encouraged to come to the meeting.

The Local Committee, co-chaired by Steve Naumann and Mickey Milner, have added an international flavor to the conference while providing us with a taste of the beautiful city of Toronto. Credit must be given to this industrious committee for their efforts in bringing in professionals from around the world to speak during four exciting international symposia. The committee also added consumer involvement to the platform presentations, asking individuals to act as co-chairs of the sessions.

I would especially like to thank Susan Leone and the RESNA staff for their year-long diligence in integrating the tasks of the Meetings Committee and making this once again the distinguished conference it is known for.

Jessica J Presperin, OTR/L, MBA
Chair, Scientific Program
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*Woodrow Wilson Rehabilitation Center*

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# Clinical Evaluation of a Multifunctional Hand Prosthesis

Yves Lozach, Sheroo Madon
Institut de Réadaptation de Montréal
Québec, Canada

**Abstract**

A multifunctional hand prosthesis designed around a new prehension geometry has been developed. With the objective to validate the prehension geometry six prototypes have been produced and tested by four amputees. To determine the outcome of the clinical evaluation a protocol comprising a selection questionnaire, and a functional evaluation procedure has been designed and used.

## Introduction

A multifunctional hand prosthesis provered from a single motor contained within the palm and designed around a new prehension geometry has been produced. The geometry and the hand functional characteristics are described in previously published papers (1) (2) and will not be discussed here. They may, however, be summarized as follows : Based on the results of ergonomic analysis of prehension (3) and on previous works with prehension orthoses, the geometry and the architecture of the hand prosthesis has been chosen to reproduce the most essential opposition movements of the thumb and some specifics prehension patterns. Designed with the aid of a 3D computer program (4) this anthropomorphic hand prosthesis consists of fours fingers and a thumb, each mobilized at the level of two joints. These fingers are adaptive i,e each one, conforms to the shape of the object and undergoes passive flexion when pushed by an external force. Two planes of mobilization at level of the carpo-metacarpal joint enable the thumb to perform tridigital prehension with an oblique plane of flexion and when externally rotated lateral prehension (see figure 1 and 2). Moreover, because the thumb's plane of flexion is oblique, the hand is also ergonomically well adapted for the cylindrical, spherical and hook grasping patterns.

## Clinical evaluation - Methodology

With the objective of validating the pattern of prehension of the new hand prosthesis, four users of a forearm myoelectric prothesis have been equipped with our new hand and have worn it for a period ranging from 4 months to 18 months. Three were tested at the Institut de Réadaptation de Montréal and one at Hugh MacMillan medical centre of Toronto. The methodology used has been based on a comparative analysis of the clinical performance between a traditional hand prosthesis, namely the Otto bock myoelectric hand prosthesis, and our hand prosthesis. This kind of approach implies that each potential candidate is an experienced and extensive user of the myoelectric prothesis. It also demands from each one an active participation in the project and ability to readjust rapidly to different patterns of prehension. With these implications in mind, an evaluation protocol was designed which comprises: a selection questionnaire that aims of at determining the profile of each user. And, a functional evaluation procedure which follows the fitting and the use of the new prosthesis for a period of a least three months. This evaluation calls upon the participation of both the occupational therapist and the user to analyse the function and performance related to two domains of activities; these are:

Fig. 1 and 2 Views of the two complementary patterns of prehension

1. The administration of two functional tests with both prosthetic hand. These tests are : "The upper extremity function test" by Carroll and the two first tests of "The Minnesota rate of Manipulation Test". These functional tests which have been created to measure manual dexterity have not been designed to evaluate a prosthetic hand; however, we have included them in our evaluation protocol in an attempt to further estimate the overall function of the upper arm and the relative amount of compensatory movements required for each test.

2. The activities of daily living as experienced by each user. The evaluation will here call upon a post-wearing questionnaire which includes subjective as well as objective data on the use of the prosthesis. The questionnaire is divided in three parts aiming to identify and analyze the functional gains and the problems experienced during these activities. The first part of questionnaire is a guiding list of activities that the unilateral upper limb amputee performs and which generally require the use of a hand prosthesis. From this list, each candidate selects the activities that concern him and gives them a performance score related to the amount of difficulty encountered. The second and third part of the questionnaire refers to the experience acquired with the new hand prosthesis and to the comparative analysis of the overall performances with each prosthesis.

## Results

Together, with the clinical evaluation, we have also proceeded with a laboratory technical evaluation which relates to the measurement of technical characteristics and the verification of the prehension geometry and functional behaviour of the prosthesis. Measured without the glove, they can be summarized as follows :

- Weight of the and prosthesis and passive wrist 540 g
- Maximum opening between the thumb and the middle finger tips 9 cm
- Closing time for the tridigital pinch 0.8 sec
- Closing time for the fist pattern 1.2 sec
- Maximum prehension force at the finger tips in the tridigital mode 45 N

Taken without the glove, these measurements meet the specified values. However taken with a commercially available glove insufficiently adapted to the morphology and the dimensions of the new hand prosthesis, some of these specifications, such as the maximum opening range and the closing and opening time of the fingers have not been met.

These weaknesses and the need to further improve the design and the long term reliability have also been confirmed by the clinical evaluation. In spite of the limited number of candidates tested, the following functional advantages were identified:

- For several activities, it reduces the use of arm and body compensatory movements during both the approach and utilisation phases of prehension.
- In many situations, it allows a better orientation of the object held for use.
- It greatly improves the object visibility, the prehension cosmesis and the grip stability, particularly for large objects.

The evaluation has also stressed the great usefulness of the lateral grip and its high level of complementarity with the tridigital prehension pattern. Furthermore, besides the possibility of achieving different grasping functions in both the tridigital and the lateral modes, the outcome of the evaluation has shown that these grasping functions can also be locked by passively flexing the fingers around the object while the thumb is mobilized by the motor. This locking feature is particularly useful for activities such as : holding a handle and carrying a suit-case.

We have noted the following modifications which have been identified or suggested by the evaluators.

- To reduce the size and the width of the hand as this will improve the hand function and cosmesis.
- To shorten the length of thumb in order to refine and increase the efficiency of the lateral grip.
- To decrease the protuberance at the base of the thumb.
- To increase the number of indexed positions of the thumb in its plane of rotation as this will increase the diversity and the number of the prehension patterns available
- To provide a wrist unit with at least two indexed flexion postures as this will further decrease the need of arm and body compensatory movements.

## Conclusion

A multifuntional and adaptive hand prosthesis has been produced and used to test our prehension hypothesis. In spite of the limited member of candidates the results have shown the potential and some functional advantages of the new prehension geometry. However, geometrical refinements and design improvements are still needed in order to fully meet the specifications and the long term reliability.

**Acknowledgements**

The authors wishes to thank Shiela Hubbard, Greg. Bush and Ihsan Al-Temen from the Hugh MacMillan Medical Centre of Toronto Canada for their participation in this clinical evaluation and their constructive comments. We also extend our thanks to the four candidates for their active collaboration.

- This research has been supported by "L'Institut de Recherche en Santé et Sécurité du Travail du Québec" CANADA Grant # RS-87-15

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(mailing address)

Yves Lozac'h
Centre de Recherche
Institut de Réadaptation de Montréal
6300, Darlington Ave.
Montréal (Québec) Canada
H3S 2S4

1.2

# USING THE EXOS HANDMASTER TO MEASURE DIGITAL RANGE OF MOTION

PL Weiss PhD OT(C), S August* MSc OT(C), G Peters** BSc OT(C) and J Sampalis** Ph.D
School of Physical and Occupational Therapy, McGill University, * Jewish Rehabilitation Hospital and ** Royal Victoria Hospital, Montreal, Canada

Clinicians involved with the assessment of injured workers are regularly called upon to evaluate the progress of the client's rehabilitation program and to determine his or her readiness to return to work. When necessary, they are also required to evaluate their permanent or partial incapacity in order to help determine eventual financial compensation and need for vocational retraining. This evaluation includes measures of range of motion and sensation as well as observations related to the loss of limbs, hypersensitivity and cosmesis. The clinician's goal is to discharge clients from therapy when the clinical evaluation demonstrates that they are capable of returning to their previous employment or that they are in need of vocational retraining.

Unfortunately, determination of the time of optimal discharge appears to be confounded by the questionable reliability and validity of some of the clinical measures. Goniometry, one of the primary measures of hand function, involves the measurement of joint range of motion with a metal or plastic protractor-like instrument. Goniometry is most suited to the measurement of passive and active joint range of motion under conditions that entail static, non-functional movements. This is clearly a significant limitation since the hands engage primarily in complex, dynamic tasks. There appear to be two major issues are of concern. First, standard goniometric records are obtained on individual joints which may be placed in mechanically advantageous positions that do not reflect their true capacity to perform functional tasks. This may result in an unduly large range of motion and a premature recommendation for return to work. Second, clients, aware of the significance of the hand assessment, may generate less than their actual active range of motion thereby increasing the time spent in therapy, the days away from work and the cost to Worker's Compensation. Clinicians try to avoid these problems by carrying out total active movement hand assessments but these produce only estimates of range of motion.

It is suggested that the use of the Exos Handmaster, an instrumented exoskeleton designed to measure angular joint rotation of the metacarpo-phalangeal and interphalangeal joints, will resolve these problems since (1) it permits the simultaneous measurement of all joints under dynamic, functional conditions and (2) its use can be integrated into the clients'. therapy routine so that repetitive and realistic performance evaluations can be achieved.

The objective of this research was to investigate the clinical feasibility of using the EXOS Handmaster to measure angular joint rotation of the digits. The work reported in this paper includes a brief description of modifications to the fixation technique used to apply the Handmaster and the results of an investigation of the unit's reliability and validity.

## METHODS

### Attachment Technique

The Exos Handmaster is a low mass (< 250 gm), Hall-effect instrumented exoskeleton designed to measure angular joint rotation of the distal (DIP) and proximal (PIP) interphalangeal joints and both sagittal and coronal plane motion at the metacarpo-phalangeal joints (MCP) (Marcus and Churchill, 1988, The 2nd Annual Space Automation and Robotics Workshop held at Wright State University). The unit is capable of recordng these data simultaneously for the thumb and any other two digits. The original unit consisted of a wrist connection assembly, stainless steel backplate and finger linkages.

Experience with the original Handmaster fixation in our own laboratory revealed a number of problems with the standard attachment technique. Subjects were uncomfortable when the velcro straps were secured to the digits. Complaints ranged from diminished blood circulation to blocking of sensation in the finger pads. Moreover, the unit did not appear to remain well placed on the dorsal surface. These concerns motivated us to make a major change to the attachment procedure which included replacement of the stainless steel backplate with customized thermoplastic molds, modification of the shape of the black hoods and the use of skin adhesives instead of velcro straps.

### Reliability and Validity Study

Eight adult subjects (five females and three males aged 21 to 38 years) with no known history of orthopedic hand dysfunction participated in this study. Subjects were selected to represent a range of anthropometric values.

Subjects participated in one 30 minute preparatory and two 90 minute experiemtnal sessions. Each subject underwent evaluations at six different positions for the MCP, DIP, and PIP joints and a maximum of four positions for MCP ulnar-radial deviation. A total of 159 observations were collected. For every joint and position combination, the measurements of range of motion were performed twice using the goniometer and then twice again using the handmaster.

All goniometric and Handmaster range of motion assessments were made by the same examiner, an occupational therapist with 14 years experience, with the last 6 years specializing in hand therapy. The Handmaster data were sampled at 100 Hz via a 16 channel A/D converter installed in a PC-AT compatible computer.

Descriptive statistics were calculated separately for the ROM measures obtained using the goniometer and the Handmaster by joint and visit. Means and 95% confidence intervals for the difference between goniometer and Handmaster measures at each tst session were also tabulated. Test-retest reliability was assessed by two methods. First, by using correlation analysis and comparison of means for the measures obtained at the two visits. The second method involved the calculation of intra-class correlation coefficients. This statistic provided a comparative evalution between the variation in outcome due to the subjects with that due to the intervention. Concurrent construct validity of the Handmaster was assessed by comparing the measures obtained using the Handmaster with those obtained using the goniometer. The same statistical methods as those used for the assessment of test-retest reliability were used for this validity evaluation.

## RESULTS

### Test-Retest Reliability

The data in Table I show the correlation coefficients for the test-retest measurements obtained separately for the goniometer and the Handmaster. These data show that the correlation coefficients were high and statistically significant (p=0.001) for both the goniometer and the Handmaster. Therefore there is a strong linear association between the measurements obtained at different times with both of these instruments.

The data in Table II describe the measurements obtained by the goniometer and the Handmaster during the test and pre-test assessments. These data show that the mean difference for the goniometer test-retest measures was significant using a paired t-test analysis but is not clinically important. The test-retest difference for the Handmaster was clinically and statistically non-significant.

Table 1: Correlational Analysis for Test-Retest Reliability

| | Goniometer | Handmaster |
|---|---|---|
| N | 159 | 155 |
| Pearson Correlation Coefficient | 0.98 | 0.93 |
| P | 0.001 | 0.001 |

Table 2: Description of Measurements (in degrees)

| | Goniometer (G) | Handmaster (H) | G - H |
|---|---|---|---|
| **Test** | | | |
| N | 159 | 155 | 155 |
| Mean | 35.1 | 43.1 | 7.2** |
| SD | 22.4 | 24.9 | 11.5 |
| Range | 2 - 97 | 1 - 115 | |
| **Retest** | | | |
| N | 159 | 146 | 146 |
| Mean | 35.1 | 44.3 | -6.9** |
| SD | 22.5 | 25.6 | 11.7 |
| Range | 2 - 94 | 1 - 110 | |
| **Test-Retest** | | | |
| N | 159 | 142 | |
| Mean | -0.8* | 0.45 | |
| SD | 4.0 | 9.1 | |

* p<0.001
** p<0.0001

Finally, intra-class correlation coefficients for the test-retest measures obtained by the goniometer and the Handmaster were 0.98 and 0.99 respectively. Both of these values were stasitically significant (p<0.0001).

### Concurrent Construct Validity of the Handmaster

The data in Table III show the correlation analysis for the measurements obtained using the goniometer and the Handmaster. These results show that the measurements obtained by these two methods had a high and statistically significant (p<0.001) linear association.

Table 3: Correlational Analysis for Construct Validity of EXOS Handmaster

| | N | Pearson Correlation Coefficient | P |
|---|---|---|---|
| Test | 155 | 0.89 | 0.0001 |
| Retest | 146 | 0.94 | 0.0001 |

The results in Table II show that the mean difference between the measurements obtained with the goniometer and the handmaster was staistically significant for both the test and re-test assessment, with the mean Handmaster measurement being higher than the mean goniometer measurement.

Intraclass correlation coefficients for the outcomes produced by the goniometer and the handmaster for the test and re-test assessment were 0.95 and 0.96 respectively. The intraclass correlation coefficient for both the test and re-test assessments was 0.95. All were statistically significant ($p<0.0001$)

## Conclusions

These results have shown that both the goniometer and the Handmaster have strong test-retest reliablity. Moreover, the data, in particular the fact that the measurements obtained with the Handmaster had a large mean and a wider range, suggest that the Handmaster is a more sensitive instrument as compared to the goniometer. Studies using the Handmaster to identify digit kinematics during dynamic functional tasks are currently in progress.

## Acknowledgements

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Patrice Weiss Ph.D, OT(C)
School of Occupational Therapy
Hebrew University
Mount Scopus, P.O. Box 24026
Jerusalem, Israel

# The Accuracy of the sensor array used in the FSCAN System

Hilarie H. Cranmer and Robert P. Patterson
University of Minnesota
Minneapolis, MN 55455

**Abstract**

The outputs from a FSCAN sen or array were recorded during four vertical cyclic loads of 25, 50, 75, and 300 pounds applied over an area of 0.5 square inches. There was a hysteresis of approximately 10% below 50 pounds of force, and a maximal difference of approximately ±20% at 100 pounds. Above 150 pounds, the output tends to flatten out.

**Introduction**

The FSCAN (Tekscan Inc., MA) is a computer based system currently used to evaluate the force and pressure distribution in the feet. The sensor has an array of 960 transducers spaced 0.1 inches apart and is fabricated on a flexible thin printed circuit with a mylar substrate. The purpose of this study was to assess the force and pressure responses of the system under different loading conditions. Two questions were addressed: Is there a hysteresis associated with the measurements and is the response of the system linear?

Maalej, et al [1] used Interlink sensors to evaluate pressures, but there was evidence of significant hysteresis and non-linearity. Tekscan reports that their system exhibits a hysteresis of 10%, a linearity of 5%, for "up" values, and a creep of 10%. They report a need for sensor "conditioning", which requires at least 12 cycles of gait in order to prevent changes in the calibration due to use. This investigation addresses the questions on linearity and hysteresis, as well as related issues on creep, repeatability, variability, and conditioning, by comparing sequential load measurements taken with the FSCAN foot sensor system.

**Methods and Materials**

Force and pressure readings were recorded using the FSCAN System. A conditioned foot sensor was used for testing and each loading occurred in the same region on the sensor. Conditioning was executed by repeatedly loading the sensor for at least 20 times with vertical pressures of at least 25 psi. To ensure only vertical loading, a rectangular box was constructed to house the sensor during loading and to support an upright pole with a loading platform for weights. At the sensor end, a circular square piece of metal was used as an actuator, to transmit the force from the weights to the sensor. The total area of the actuator was 0.5 square inches and its flat surface was covered with Johnson & Johnson's mole skin tape, typically used to cover casts.

In order to assess the question of hysteresis, two tests were performed. In the first, the sensor was loaded to 300 pounds, then unloaded. This weight was chosen to represent 50% of maximum loading capacity, specified at 1500 psi. Two recordings were taken: one immediately after loading and the other, one minute later. This test was performed again to establish repeatability. In the second test, the sensor was sequentially loaded to 25 pounds, then unloaded back to zero. This cycle was repeated for weights of 50, 75 and 100 pounds.

The remainder of the tests evaluated sensor-to-sensor variability and conditioning effect. To determine conditioning, a new sensor was loaded 20 times with a 25 pound weight. Measurements were recorded after the load was applied for one minute. The outputs from two conditioned sensors were recorded and compared.

**Results**

The results are reported in terms of force. The pressure varied in direct proportion to the force because the same loading area was used throughout the study.

Figure 1 shows the sensor response to the cyclic loadings. There is a moderate non-linearity evident, as well as a slight hysteresis. In figure 2, which shows loads up to 300 pounds, the non-linearity is far more significant. It is also shown that there is no significant difference in sensor repeatability.

The average value for the new sensor after 20 repetitive loadings with a 25 pound weight was 22.0 pounds. The average value for another conditioned sensor was 13.0 pounds, which reflects a constant difference in calibration between sensors. There was no significant change with repeated loadings. The average force of the first five loadings of the new sensor was 23.0 pounds and the average force of the last five repetitions was 22.0 pounds.

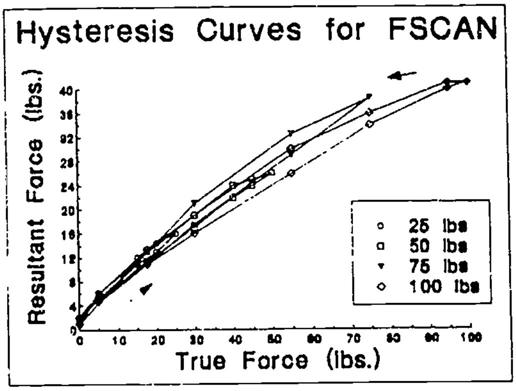


Figure 1. Force values for cyclic loadings of 25, 50, 75, and 100 pounds, using an actuator with an area of 0.5 square inches

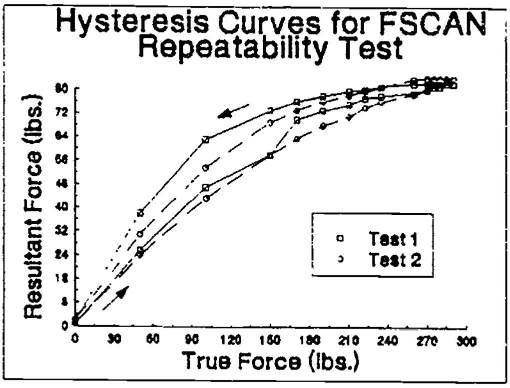


**Figure 2.** Force values for a cyclic loading of 300 pounds, conducted twice.

#### Discussion

Although Tekscan reports a linearity of 5% for "up" values, this study shows a greater difference in linearity through calibration with individual sensors. A different calibration system has been recently installed by Tekscan (January 92), but has not yet been tested by this research group.

The hysteresis reported in this study falls within range (10%) for loading below 50 pounds, but has a maximal value of approximately ±20% at 100 pounds. This evidence of non-linearity and hysteresis is consistent with the results reported by Maalej[1], for the Interlink sensors. Although these results show moderate hysteresis, they probably do not contribute to serious error in normal clinical use

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Mailing Address Robert Patterson
University of Minnesota Hospital
UMHC Box 297
Minneapolis, MN 55455
612-626-4395

# A Video System for Real-Time Synchronization of Muscle Activity and Joint Moments During Gait

James J. Carollo, M.S.
Mobility Research and Assessment Laboratory / Department of Orthopaedic Surgery
University of Texas Southwestern Medical Center at Dallas
Dallas, Texas 75220 USA

## ABSTRACT

This paper will describe the design of a new measurement system which synchronizes electromyographic (EMG) waveforms and/or ground reaction force vectors with video of a walking subject in real-time. The overall system utilizes conventional video and computer equipment, a commercially available EMG recording system, a three component force platform, and specially designed hardware and software to provide a unique composite display combining gait data with video of the subject. All data is simultaneously recorded to disk, so that summary reports of EMG and force platform data can be generated to accompany the video record. The system is especially useful for teaching since it presents estimates of EMG envelopes and joint moments in an extremely visual manner. This has been found to be more readily understood by the clinician and by all students of gait analysis.

## BACKGROUND

The clinician can choose from a wide variety of measures when evaluating the gait performance of a subject. Often, the measurements selected are related to the understanding and interest of the investigator and the logistical support available [Winter, 1987], with the greatest attention placed on the so called "outcome" measures" (e.g. kinematics, stride length, cadence, ground reaction forces). These measures are useful for quantifying overall gait performance, but unfortunately reflect the result of many integrated output effects. Outcome measures alone will not permit identification of the primary cause of a gait deviation.

In order to address the fundamental cause of a particular gait abnormality, attention must also be given to those measures which describe the action of the muscles and their ability to produce appropriate levels of torque about each joint of the support limb. It has been shown, however, that both EMG patterns [Arsenault et. al., 1986] and joint moments during stance [Winter, 1984] are highly variable, especially in subjects whose gait pathology is the result of a CNS disturbance such as stroke or head injury, or musculoskeletal alterations associated with amputation or joint surgery [Winter, 1990]. This inherent variability is evidence of the remarkable adaptability of the neuromuscular system, and only by scrutinizing the subtle interaction between motion, muscle activity, and joint torques can insight be gained into a complex gait problem.

Since variations often occur on a step by step basis, conventional analytical techniques such as ensemble averaging may obscure important adaptations of the CNS to a momentary disturbance in balance, cadence, or base of support. One method for circumventing this analytical difficulty is to record on a common time base measurements of motion, muscle activity, and joint torque in a manner which maintains the inherent synchrony of each measurement.

The system described in this paper attempts to accomplish this in a highly graphical fashion. The approach uses video to provide a common time base along with a view of the subject's motion, while overlayed computer graphics provide real-time estimates of EMG envelopes and joint moments. To accommodate the rapid screen refresh requirements of real-time video, the joint moment descriptions rely on a graphical technique known as "force line visualization" [Cook et. al., 1979], where the ground reaction forces are represented as a resultant vector emerging from a point in the video field corresponding to the instantaneous center of pressure. The current design expands on a video/EMG system developed over ten years ago [Carollo, 1982] utilizing several updated measurement techniques and more novel technology.

## RATIONALE

A more graphical approach to the problem of data synchronization was selected over a simple multiplexed data collection system after considering the needs of the principle end users of the system; clinicians whose primary training in gait analysis focuses on the visual assessment of gait. The system developed can present complex data in a manner readily understandable to individuals confused by conventional biomechanical descriptions, and is accessible to anyone who can operate a home VCR.

## DESIGN

The basic design consists of four fundamental subsystems, each of which can be used individually or in combination with the others (see figure). They are the video subsystem, the EMG measurement subsystem, the ground reaction force (GRF) measurement subsystem, and the graphic overlay subsystem. In the descriptions which follow, most of the component devices will be described generically without reference to a specific manufacturer, since in most cases there is no inherent superiority of one brand over another. In those cases where only one manufacturer's product can be used, it will be so noted.

### Video subsystem

The video subsystem is used to record and playback the movements of the subject from the front, the side, and underneath; the latter by way of a glass floor section. It also provides a common time base for all other measurements, corresponding to the 60 Hz (16.67 ms) video field rate. Three electronically shuttered, CCD, color video cameras with approximately 700 lines of horizontal resolution are used to obtain high quality images of the subject while walking. Camera control units for each camera permit synchronization of the three video signals in addition to video setup and remote selection of electronic shutter speed. Video outputs from each camera control unit are routed to a special effects generator which permits selection of any camera or a split screen between any two. The resulting composite video is then routed to a S-VHS video cassette recorder for initial data recording. Additional equipment includes an editing VCR to facilitate the reduction of raw video to a finished product, a character generator for screen annotation, an assessment VCR with digital frame storage for clear slow-motion review, and several color monitors for playback purposes.

EMG measurement subsystem
Electrochemical potentials associated with a skeletal muscle's contraction are detected using either infant size disposable ECG electrodes or 50 micron platinum fine wire electrodes arranged in a bipolar configuration along the long axis of the muscle to be studied. Each electrode pair is connected to a miniature amplifier/transmitter which provides wireless transmission of EMG activity to recording equipment a short distance away from the subject. Individual footswitches, made from InterLink Force Sensitive Resistors ™, are attached to the heel, fifth metatarsal, first metatarsal and great toe of both feet. Switch closure events are encoded to resemble an EMG signal, so that an available EMG channel can be used to transmit foot/floor contact data to the recording equipment. Once transmitted, bandpass filtered EMG (30 - 1500 Hz) and decoded footswitch data are recorded at 3KHz/channel using a data acquisition system based on a Dataq Instruments CODAS™ board in a 386 class personal computer. Special software written in the C programming language controls data acquisition, real-time display of scrolling EMG waveforms and footswitch events, and storage of data to disk at a total throughput of 30KHz Although not essential to the system described in this paper, the data files produced can be converted into an appropriate file format so that they can be used with commercially available EMG analysis software.

GRF measurement subsystem
Ground reaction forces are obtained in the conventional manner using a glass top, three component force platform mounted on parallel steel girders across a five foot camera pit. After signal conditioning and amplification, eight analog channels are recorded using a similar but independent data acquisition system from the one described in the previous section. Special software was developed to (1) read the eight analog force platform channels, (2) calculate the instantaneous forces Fx, Fy, and Fz, and coordinates of the center of pressure, ax and ay, (3) calculate the appropriate vector projection and (4) draw the vector originating from the center of pressure in the sagittal view of the computer display. This procedure was then repeated for the coronal view. In order to maintain a continuous graphic display which could be updated in accordance with changes in the force platform output, all procedures were completed during each vertical retrace period.

In addition to these real-time software modules, separate procedures were developed to accommodate different camera positions, scaling of the force vector for different fields of view, and standard data acquisition of ground reaction force data. As in the EMG measurement subsystem, data files produced in this module could be easily converted to be compatible with third party analysis software.

Graphic overlay subsystem
This final subsystem is responsible for integrating the three previous subsystems into a cohesive unit, and therefore must overcome the inherent incompatibilities of each data format. Specifically, this subsystem must

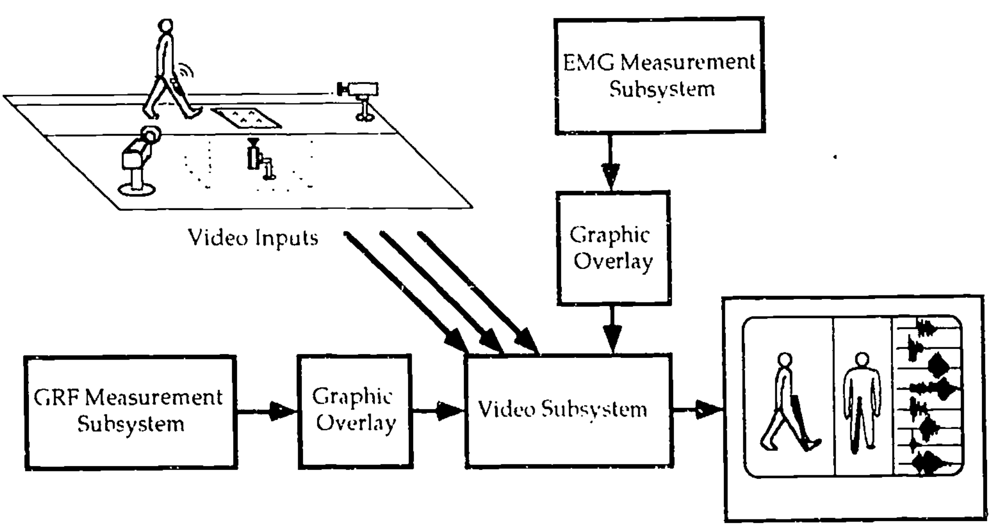


Figure #1: System Block Diagram

convert VGA computer graphics into NTSC composite video so that synchronization pulses from the video subsystem can be used to trigger the displays of the two independent data acquisition systems. Once this is accomplished, creation of the final video display is simply a matter of generating an appropriate key signal from the data acquisition displays, and inserting this key into the video subsystem's data stream.

In the present system, this was accomplished using tools from the emerging fields of multimedia and desktop video production. Genlockable VGA display boards compatible with each data acquisition system were installed in their respective computers, and configured for a high contrast overlay. Synchronization pulses in the form of a standard black burst signal were used to trigger each board, with the video output daisy-chained to produce a composite key signal in sync with the original video. By selectively turning on the key signal in each board, one can produce a video/EMG display, a video/ force-line display, both overlays, or none at all. This level of flexibility permits the operator to configure a display system which matches the specific needs of each clinician using the system, and allows different displays for different clinical protocols.

## EVALUATION & DISCUSSION

The present system has been in place since August of 1991, and in general has been accepted by the clinical community. The principle advantages are related to the intuitive nature of the display, which promotes easy correlation between a subject's motion and their EMG activity, and/or joint moment requirements.

However, there are certain inherent limitations to the system which cannot be overlooked. First, the video subsystem does not provide quantitative measurements of joint position, and serves primarily as a means for facilitating frame-by-frame visual analysis of the walking pattern. Second, EMG signals must be presented in their raw, unprocessed form since timing requirements for real-time display limit the amount of signal processing which can be performed. Envelopes of EMG activity must be estimated from amplitude changes in the waveform, and thus are only useful for determining periods of muscle activity from periods of reduced activity. Finally, force-line visualization as a predictor of joint moments is useful as a clinical estimate, but care must be taken when using the method in normals or faster speed walkers [Wells, 1981]. This is because joint torque is determined by visually comparing the line of action of the ground reaction force and the apparent joint center of the joint of interest, to subjectively determine a moment arm /vector amplitude product. This estimate becomes less accurate as one progresses up the kinematic chain from ankle to hip, since gravitational an inertial forces of each limb segment are neglected, and the contribution of these forces to the overall ground reaction force increases as one gets further from the ground. To further complicate the analysis, predicted moments are opposite in sign from the actual joint moments, and therefore must be considered as a "demand moment," which necessitates an equal and opposite joint moment to counteract it

Although the system in no substitute for traditional quantitative measures of EMG and joint moments, we feel there is still a place for this type of system in the clinic. It is quite useful as a first step in the gait assessment procedure, and is sensitive to subtle changes in the patient's gait which may be obscured by traditional analysis. Perhaps its best application is in teaching allied health students and those new to gait analysis a systematic approach to the problem. And like any clinical assessment tool, it is only as good as the clinician who uses it.

## ACKNOWLEDGMENTS

The author wishes to acknowledge the important contributions of Mr. Glenn Blackwood, for developing software for the force-line visualization module, Mr. John Samford, for his ongoing technical and operational assistance, and Dr. James W. Aston, Jr. for his support during the development of this facility. This work was supported in part by the generous contributions of the Mobility Foundation, the Southwestern Medical Foundation, and the Dallas Rehabilitation Institute.

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Please address correspondence to:
James J. Carollo, M. S.
Mobility Research & Assessment Laboratory
9705 Harry Hines Blvd , Suite 105
Dallas, TX 75220 USA

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# A Test to Determine Dynamic Exercise Capacity and Autonomic Cardiovascular Function in Individuals with Multiple Sclerosis.

Janet A. Ponichtera, Thomas Mathews, Roger M. Glaser & Bertram N. Ezenwa
Veteran's Affairs Medical Center, Institute for Rehabilitation Research & Medicine, Wright State University
Dayton, OH USA

## ABSTRACT

Determination of abnormal autonomic cardiovascular function (ACF) in persons with multiple sclerosis (MS) has traditionally used quiescent, perturbations. This study examined the use of dynamic leg cycling exercise as an index of exercise capacity and ACF in this population. For this, heart rate (HR) and blood pressure (BP) responses to 3 standard, quiescent tests and during an incremental leg exercise protocol were determined. Eighteen MS subjects (minimal-moderate impairment) were matched to 18 non-MS persons. Results of the quiescent ACF tests showed no abnormal responses in the MS group. During cycling exercise, HR and systolic BP (SBP) adjustments to oxygen uptake ($\dot{V}O_2$) increments during absolute exercise power outputs (PO) were not significantly different between groups. Examination of HR and SBP at relative $\dot{V}O_2$ showed this minimally- impaired MS group to have a slightly attenuated HR response but a near identical SBP response vs the non-MS group. More severely impaired MS individuals would might respond differently This dynamic exercise protocol may offer more insight into the affects of MS upon ACF and provide guidance for determining rehabilitation potential of this population.

## INTRODUCTION

Dysfunction of the autonomic nervous system in multiple sclerosis (MS) has been well-documented with manifestations occurring in bladder,[1] sexual,[1] and sudomotor[7] function. Traditionally, documentation of autonomic cardiovascular function (ACF) of both sympathetic (SYMP) and parasympathetic (PARA) reflexes in persons with MS have been via standard tests with the patient in a quiescent state. Standard tests such as the Valsalva maneuver, rhythmic deep breathing, and sustained isometric handgrip are only 3 among several acute, perturbations performed under quiescent conditions in an effort to isolate and measure autonomic cardiovascular responses of heart rate (HR) and blood pressure (BP). While several investigators have found a relatively high incidence of abnormalities in PARA and/or SYMP ACF tests with this population,[8,9,10] others have not.[2,8] What these tests reveal is important; however, they do not exhibit information on dynamic exercise capacity and whether cardiovascular responses in a particular individual are sufficient to sustain greater cardiovascular organ system demands. For example, any daily activity, whether it be for work or pleasure, requires a constant metabolic demand which must be supported by adequate central (HR) and peripheral (BP) cardiovascular adjustments. Such adjustments are predominantly controlled by the sympathetic and parasympathetic nervous systems. As such, knowing whether these responses are sufficiently intact to support dynamic activity in the MS patient is of equal importance. Such information may provide even greater insight into a patient's rehabilitation potential. Therefore, the purpose of this study was to develop an easily administered protocol of dynamic exercise (i.e. leg cycling) that could be used in suppliment to existing standard, quiescent ACF perturbations, to examine MS individuals under conditions that are more similar to the demands required during normal daily activity.

## PROCEDURES

**Subjects**. Eighteen persons who had been positively diagnosed with MS were examined by a neurologist and rated on the Expanded Kurtzke Disability Scale.[6] Distribution of ratings is presented in Table 1. Individuals having a minimal to moderate level of impairment were selected for participation to assure their ability to physically perform the dynamic leg cycling protocol. The length of time from the date of diagnosis ranged between 1 and 23 yr ($\bar{X}$ - 6.2 yr ±6.3). A group of 18 healthy, non-MS participants (AB) were matched to the MS group on the characteristics of age, gender, height, and weight. Further description of group characteristics is presented in Table 2. The presence of any cardiovascular, pulmonary, renal, metabolic or non-MS orthopedic disorder excluded participation. Informed Consent was obtained from all participants according to University policy.

Table 1. Distribution of EDSS Ratings Among MS Subjects.

| EDSS Rating | 1.0 | 2.0 | 3.0 | 4.0 |
|---|---|---|---|---|
| No. of Subjects | 7 | 4 | 5 | 2 |

Table 2. Subject Characteristics.

| Group | MS (n = 18) | non-MS (n = 18) |
|---|---|---|
| Age (yr) | 39.6(±5.1) | 37.7(±5.0) |
| Height (cm) | 171.2(±11.0) | 171.8(±10.2) |
| Weight (kg) | 73.3(±15.5) | 75.6(±15.8) |

Tests of Autonomic Cardiovascular Function (ACF). Three non-invasive tests of ACF, which monitored HR and diastolic blood pressure (DBP) responses at rest, were administered. These tests have been described previously and widely used.[3] The test perturbations and monitored responses were: the Valsalva maneuver - HR; deep rhythmic breathing - HR (E:I Difference); and sustained isometric handgrip contraction - DBP. The first two, which use HR, are considered PARA tests, whereas, the third which uses DBP, is considered a SYMP test. Subjects were connected via chest electrodes to a Hewlett Packard 78324A ECG monitor which recorded HR during all tests. This was interfaced with a computer via an A/D converter. R-R intervals were calculated via the computer program and converted into numerical values and compared to published standards for *normal-borderline-abnormal* responses. This computer system has been full described previously.[4] BP was determined using an automated sphygmomanometer connected to another channel of the aforementioned ECG monitor. BP recordings were manually entered into the computer following the test session.

Leg Cycling Protocol: Following a 5-min rest period, subjects performed a discontinuous, progressive intensity protocol of recumbent leg cycling. Power outputs (PO) began with no flywheel resistance at a pedal frequency of approximately 50 rpm. Absolute increments of approximately 25 W were added during each subsequent stage. Each exercise stage lasted 4-5 min, with a 3-5 min rest between stages. Cardiorespiratory and metabolic data were acquired via open circuit spirometry. HR was monitored constantly using a $CM_5$ electrode placement, with recordings each min. DBP and systolic BP (SBP) was obtained manually during the final min of PO using a standard sphygmomanometer. Following the 4 submaximal stages, a final continuous maximal effort stage of approximately 4 min was performed, with increments in PO each min. Subjects were asked to maintain a pedal frequency between 50-60 rpm. The test was terminated due to volitional exhaustion or predetermined metabolic and pulmonary indices concomitant to an increase in PO.

## STATISTICAL ANALYSIS

A Student's *t*-test was used to determine differences between groups on physical characteristics. Absolute values of cardiovascular and metabolic data, as well as absolute and relative increments in PO during cycling, expressed as a percentage of each individual maximal PO ($PO_{max}$) were compared using a 2 X 5 Repeated Measures Analysis of Variance. A *post-hoc* Duncan was used to determined interactions between groups and stage with respect to the various dependent variables. Correlation analysis was used to determine the relationship among cardiovascular, metabolic, and PO variables specific to each group.

## RESULTS

There were no significant differences between groups with respect to age, height or weight ($p > 0.05$). The results of the tests of quiescent ACF tests are presented in Table 3. No MS subject exhibited an abnormal HR response to the two PARA tests. During the one SYMP test of DBP, 83% showed a normal increase in response to the sustained isometric contraction. Only a small percentage (11% and 17%) exhibited a borderline response to the PARA and SYMP test, respectively.

Both maximal PO and maximal oxygen uptake ($\dot{V}O_{2max}$) were lower for this MS sample. HR and SBP responses in relationship to oxygen uptake ($\dot{V}O_2$) at the various absolute POs are illustrated in Figures 1 and 2, respectively. Both cardiovascular responses increased in a linear fashion and were similar to those elicited from the non-MS group. SBP for the MS group appeared to be slightly higher at each exercise stage when compared to absolute values of $\dot{V}O_2$; however, when HR and SBP responses were compared at relative $\dot{V}O_2$, (i.e. at a percentage of an individual's $\dot{V}O_{2max}$) HR response was slightly lower for the MS group and SBP was almost identical to the non-MS group. Correlation analysis among the metabolic and cardiovascular variables for the MS subjects produced significant, positive correlations ranging from R=.96 to R=.99, ($p<.01$). Similar significant positive correlations were seen for the non-MS sample ($p<.01$).

Table 3. Summary of 3 ACF tests performed by MS subjects under quiescent, standardized conditions.

| Test | Response | | |
|---|---|---|---|
| | Abnormal | Borderline | Normal |
| Valsalva Maneuver | 0 | 0 | 18 |
| E:I Difference | 0 | 2 | 16 |
| Sustained Contraction | 0 | 3 | 15 |

Figure 1. HR response compared to absolute oxygen uptake in MS and non-MS subjects during leg cycling.

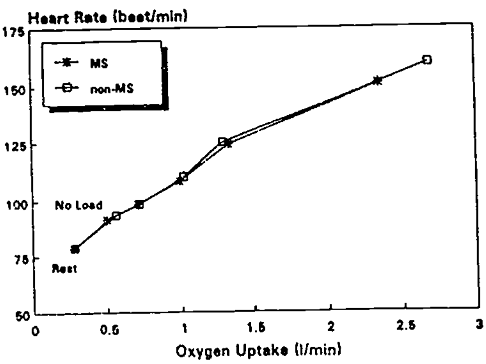
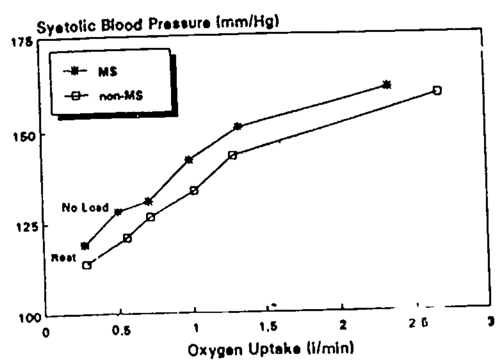



Figure 2. SBP response compared to absolute oxygen uptake in MS and non-MS subjects during leg cycling.





DISCUSSION

This study illustrates that in a sample of MS persons who have a minimal to moderate level of impairment, results of standard, quiescent ACF tests are predominantly normal. HR and SBP responses elicited during a dynamic exercise test support these findings. Again, it should be noted that the lack of abnormal responses from this group may be directly related to the distribution of impairment level in the sample.

Previously, Senaratne, et al.[11] found ACF abnormalities in HR and SBP in an MS group who ranged from minimal to severe in level of impairment (i.e. EDSS). Their sample's abnormal performance during the Valsalva maneuver and rhythmic deep breathing were substantiated by attenuated HR and SBP responses during an incremental protocol of arm crank ergometry. As previously noted, a factor that may have contributed to both the abnormal ACF responses on the standard tests as well as during the arm exercise protocol is the fact that 57% of their sample were more disabled than the sample used in the present investigation. Furthermore, 23% of their sample were unable to perform even the lowest increment in PO of the arm exercise protocol. Although a clear relationship has not been established between level of impairment (i.e. EDSS) and incidence of abnormalities in ACF, part of the problem may exist in the types of scales (ordinal) upon which these two variables are rated, rather than the lack of an actual relationship. Since these investigators did not provide absolute PO data with respect to specific HR and SBP responses nor did they measure the metabolic demand during the exercise protocol, it is difficult to appreciated their results fully. It is possible that a more impaired sample may have a much lower exercise capacity due to loss of innervation to working muscles rather than insufficient cardioregulatory adjustments. However, whether their MS sample's poor performance, was due to abnormal support by central and peripheral ACF can only be hypothesized at this time.

While the maximal exercise capacity and $\dot{V}O_{2max}$ of the MS sample in the present investigation was significantly lower than the non-MS control group, this deficiency was probably not severe enough to interfere with the demands of daily function. However, with exacerbations and further decerases in exercise capacity and $\dot{V}O_{2max}$, the ability to perform these activities would be compromised. The fact that both HR and SBP increased linearly with each additional submaximal PO increment and metabolic demand illustrates that these particular MS individuals would be able supply adequate cardiovascular support for metabolic demands, such as those required during activities of daily living, employment and and/or sport and leisure. It is likely that the slope of these cardiovascular responses would be lower in more severely impaired MS patients due to greater SYMP and PARA damage resulting in abnormal ACF.

Utilization of this type of dynamic exercise test could enhance our understanding of the affects of MS upon autonomic cardiovascular function in this population. Standard, quiescent tests serve to identify the possible existence of an ACF abnormality, while a dynamic exercise protocol places more demands upon the cardiovascular system, requiring more sympathetic stimulation. and thereby increasing test sensitivity. Thus, autonomic dysfunction that occurs with MS may be more easily identified with dynamic exercise testing since organ system reserve is reduced. Disease progression may be tracked with more accuracy by periodically repeating standardized dynamic exercise tests.

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Janet A. Ponichtera
Institute for Rehabilitation Research & Medicine
Wright State University
3171 Research Blvd.
Dayton, OH 45420

# Therapeutic Effects of Vestibular Stimulation on Cerebral Palsy: A Control Systems Viewpoint

James W. Fee, Jr., MS and Katherine T. Samworth, BEE
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

## ABSTRACT

Vestibular stimulation is a therapeutic technique widely used in the treatment of neuromuscular dysfunction such as cerebral palsy. Based on a review of the anatomy and physiology of the vestibular system and its connections, a theory is offered to explain why vertical vestibular stimulation may be of greatest benefit. This theory is discussed from a control systems viewpoint in an attempt to explain the effects of this form of stimulation from an engineering perspective.

## INTRODUCTION

Cerebral Palsy (CP) is a persistent motor disorder caused by non-progressive damage to the central nervous system, which most often occurs before or during birth. Vestibular stimulation in the form of swinging, rolling, and rhythmical rocking is used in rehabilitative therapy to help inhibit abnormal motor responses and facilitate normal motor responses in those with CP. Therapists such as Bobath, Ayers, and Rood agree that the vestibular system plays an important role in treatment. Bobath[3] uses "neurodevelopmental techniques" to elicit equilibrium and righting reactions which rely on output from the vestibular apparatus. Ayres[2] states that the vestibular receptors are the most sensitive of all sense organs. She claims that vestibular stimulation, such as rocking, tends to organize the brain. Rood[5] advocates the use of slow rocking, to stimulate the labyrinths (a part of the vestibular appaiatus) in her treatment techniques. More recently, therapeutic horseback riding has become a popular method of providing vestibular stimulation. The literature has reported various benefits in using this type of therapy

Although therapeutic effects of all types of vestibular stimulation have been recognized for sometime, a review of the literature has produced little scientific evidence that identifies the source of such benefits. The authors will present a physiological review followed by an explanation, from a control systems viewpoint, to help justify the therapeutic use of vestibular stimulation, specifically, vertical linear oscillations.

## ANATOMY/PHYSIOLOGY

### The Vestibular System

The vestibular apparatus is made up of the semicircular canals (also know as the labyrinths), which respond to angular acceleration, and the otoliths, which respond to linear acceleration. These organs convey information to four vestibular nuclei via the vestibular nerve. Of these, the lateral vestibular nuclei (LVN) receives most of its information from the otoliths. The LVN gives rise to the vestibulospinal tract (VST) which descends the length of the spinal cord. Fibers from the VST form excitatory synapses with alpha motoneurons innervating muscle and gamma motor neurons innervating muscle spindles.

### The Muscle Spindle

The muscle spindle is a specialized form of muscle fiber that contains both sensory and motor elements. The sensory elements are made up of centrally located nuclear bag fibers and longitudinally distributed nuclear chain fibers. Both contain motor elements at their ends. The nuclear bag fibers are innervated by gamma 1 (dynamic gamma) motor fibers and the nuclear chain fibers are innervated by gamma2 (static gamma) motor fibers. Two types of receptor endings are found in the sensory portion of the spindle. The primary endings, which originate in the bag and chain fibers, respond to length and rate of change in length of the muscle. The secondary endings, which originate only the nuclear chain fibers, respond to length only. (see Figure 1.) It is assumed that the chain fibers are responsible for afferent information regarding the static response, or length, of the muscle and the bag fibers, the dynamic response, or the rate of change of muscle length.

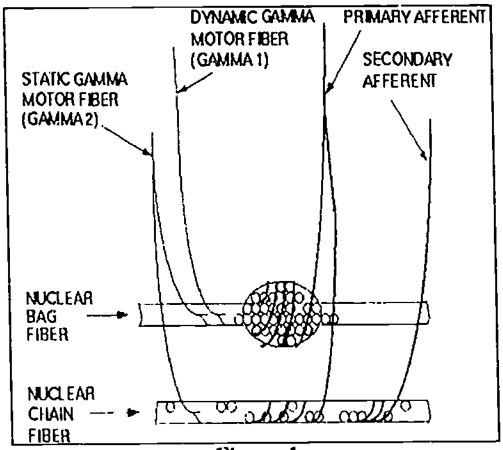


**Figure 1**
**Muscle Spindle**

Excitation of the nuclear bag fibers by the gamma 1 neurons will enhance the dynamic response of the spindle, while excitation of the nuclear chain fibers by the gamma 2 neurons will enhance the static response of the spindle.

### Vestibular Influence on Muscle Spindles

As previously stated, fibers from the VST make synaptic connections with the gamma motor neurons. According to Pompeiano[11], this synaptic connection is formed exclusively with the gamma 2 or static gamma motor neurons. This would suggest that the function of the vestibular-muscle linkage is to increase the sensitivity of the muscle spindle to length, or more importantly to the sense of position of the limbs in space, the proprioceptive sense. The link between the vestibular system and muscle spindle is depicted in Figure 2.

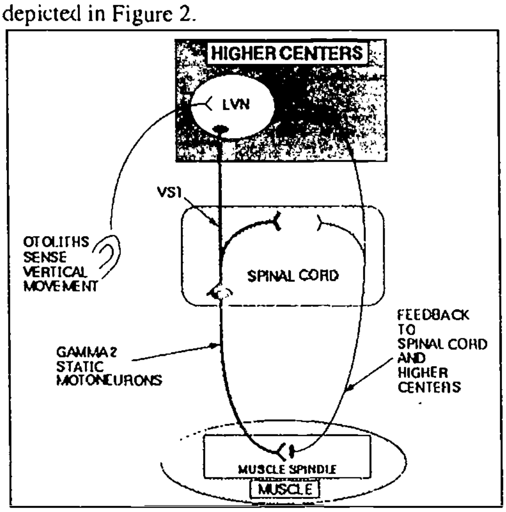


Figure 2
Vestibular - Spindle linkage

While Pompeiano's studies were done on cats, several others have implied that there is a similar functional relationship between the vestibular apparatus and the muscles in man. Aiello et. al.[1] reported changes in alpha motor neuron excitability when subjects were tilted. Studies done by Szturm et. al.[12] support the view that there is a functional linkage between otolith signals and activity in lower limb muscles in humans. Chan [4] demonstrated changes in soleus motor neuron excitability in response to variations in head position. He linked these changes directly to the otolith afferents. Greenwood et. al.[6] reported that upon falling vertically, humans show increased reflex activity of the ankle. They theorized that falling stimulates the otoliths which in turn facilitates supraspinal pathways leading to excitation of the muscle spindles. These studies suggest a functional link between the vestibular system and the muscle spindles in humans.

Based on this review of the anatomy and physiology of the vestibular apparatus and its connections with the muscular system, the authors wish to propose the following hypothesis.

## HYPOTHESIS

Linear vertical vestibular stimulation causes sensory information from the otoliths to reach the gamma 2 motor neurons through the LVN and the VST at all levels of the spinal cord. Such stimulation may increase the sensitivity of the muscle spindle, specifically the static response which is responsible for position sense. In short, otolith stimulation may enhance proprioception.

## APPROACH

In order to understand the implications of the influence of otolith organs over the control of movement, it is helpful to approach limb position control from a control systems viewpoint. In so doing, it becomes clear how the muscle spindle might influence motor control and in turn how vestibular stimulation can affect that influence.

### The Role of Feedback in Control Systems

Human motor control has often been modelled as a feedback system which functions as a position servomechanism. In such a system the output "position" is monitored and "fedback" to the controller. The controller then uses this information to keep the system at a desired position. A servo-mechanism controls position by causing the output of the system to be as close to the input as possible.

### Feedback Control and the Stretch Reflex

The monosynaptic stretch reflex is an excellent example of a feedback control system. A force on the muscle causes it to stretch. This change in length causes the spindles to fire, sending excitatory signals to the alpha motor neurons. This causes the muscle to shorten, which will continue until the muscle is back to its original position in turn causing the spindles to stop firing. The block diagram of Figure 3 can be used to

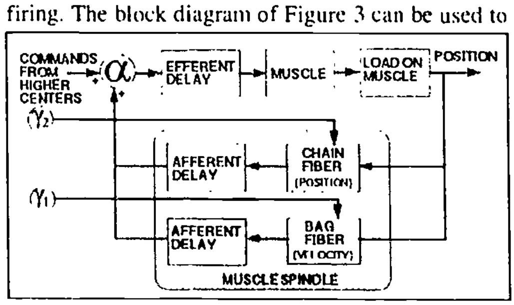


Figure 3
Stretch Reflex Block Diagram

describe the feedback control of the stretch reflex. In this diagram the "α" motor neuron (the controller) is set with a position via a command from "higher centers". This position is maintained with the use of feedback through the muscle spindles.

### Control Theory and Cerebral Palsy

Control theory can help open up the door to understanding more about disorders such as CP. One view of this disorder suggests that a faulty feedback loop could be responsible for certain abnormal movements seen in CP. Harris suggests that:

> "In theory, all deviations of muscle tone observed in cerebral palsy.... can be explained in terms of derangements in muscle spindle stretch receptor sensitively". [7]

McCloskey[10] states that ones ability to control movement depends on kinesthetic sense. If muscle spindles are responsible for kinesthetic sense, or proprioception, as suggested earlier, then a malfunction of the sensory feedback could be the cause of diminished proprioception seen in many with CP. Nielson's[10] work with athetoid CP subjects suggests a relationship between a faulty feedback control system and athetotic movements. His studies imply that the cause of these abnormal movements is an underdamped closed loop control system. From a control systems viewpoint, underdamping implies an alteration in the gain of a feedback loop. It is precisely this "control of gain" that Matthews[9] suggested as the role of the gamma motor system. It could be that a malfunctioning gamma motor system may be the cause of faulty stretch receptor sensitivity. This could result in too much or too little position or velocity feedback traveling around the loops thus causing abnormal motor responses.

By looking at neuromuscular dysfunction from a control systems viewpoint, an attempt can be made to explain why signs, such as decreased proprioception, abnormal stretch reflexes, and abnormal motor responses are seen in those with cerebral palsy. It is possible that a faulty feedback loop, specifically abnormal stretch receptor sensitivity could be the direct cause these abnormal signs. If muscle spindles are responsible for proprioception, then abnormal stretch receptor sensitivity could cause an alteration in this sense. Faulty stretch receptor sensitivity could also be the cause of abnormal stretch reflexes. Alteration of the gain in the feedback loop which leads to underdamping of the system may again be responsible for abnormal movement seen in those with CP.

### The Role of Vestibular Stimulation

It was suggested at the end of the anatomy/physiology section that vestibular stimulation may change the sensitivity of the muscle spindle. If the abnormal proprioception, and abnormal stretch reflexes, often seen in those with CP is caused by faulty sensory feedback, as was earlier suggested, then vestibular stimulation, specifically in the form of vertical oscillations, may help to enhance the natural feedback systems of those with CP by biasing it to a more normal level.

## DISCUSSION

Vestibular stimulation is used as a treatment technique in many clinics. However, more needs to be done to totally justify and explain its use. Based on anatomical and physiological evidence the authors have used methods from feedback control theory in an attempt to explain why vestibular stimulation, specifically in the form of vertical oscillations, is beneficial and should be investigated as an important therapeutic intervention in the treatment of CP.


## ACKNOWLEDGEMENT

Funding for this research was provided by the Nemours Foundation.


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James W. Fee, Jr. and Katherine T. Samworth
Applied Science and Engineering Laboratories
Alfred I. duPont Institute
P. O. Box 269
Wilmington, DE 19899
Phone: (302)651-6830

1.7

# Mathematical Modeling: A Tool for Cerebral Palsy Investigations


**James W. Fee, Jr., MS.**
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA



## ABSTRACT

An approach to the use of mathematical modeling of the neuromuscular control system to gain greater insight into an understanding of cerebral palsy is presented. The paper describes how optimization techniques might be used to shed light on the mechanisms whereby vestibular stimulation has a therapeutic influence on those with this disability.


## INTRODUCTION

Advances in mathematical modeling of neuromuscular systems in recent years has provided much in the way of insight into how various levels of the nervous system might function. To date, most of this work has been applied to the understanding of the intact nervous system. The purpose of this paper is to show that these models are now at a point where they offer opportunities to gain greater insight into the pathology of neuromuscular disabilities. In particular, it is believed that a great deal can be gained from the application of systems modeling to various phenomena observed in the cerebral palsy clinic which are, at present, poorly understood.

One phenomenon, which is the basis for the present work and the motivation behind this paper, is the effect of vestibular stimulation on those with cerebral palsy. This effect, which is to change the tone of the muscles, has been noted by many authors and comprises an integral part of most therapy programs for those with this neurological disability.

If the clinician is to make optimal use of vestibular stimulation, there must be a complete understanding of both the physiological mechanisms by which the desired change in tone is effected and the means by which the effect can be maximized.

In a separate paper [2] the author outlined the physiological basis for an hypothesis suggesting that vertical oscillations might be one of the more productive forms of vestibular stimulation. In this paper an avenue of research will be proposed, directed not only at demonstrating that this theory is correct, but also to shed light on the nature of the change which takes place during the use of this form of therapy.

## BACKGROUND

In attempting to gain insight (from a control systems viewpoint) into the effects of vestibular, or any form of stimulation, on the overall tone of muscles, it is useful to separate out the spinal level control mechanisms from the influence of higher centers of the central nervous system. Such a separation allows one to view the muscles and neurons controlling a single joint as a Joint Angle Control System with the

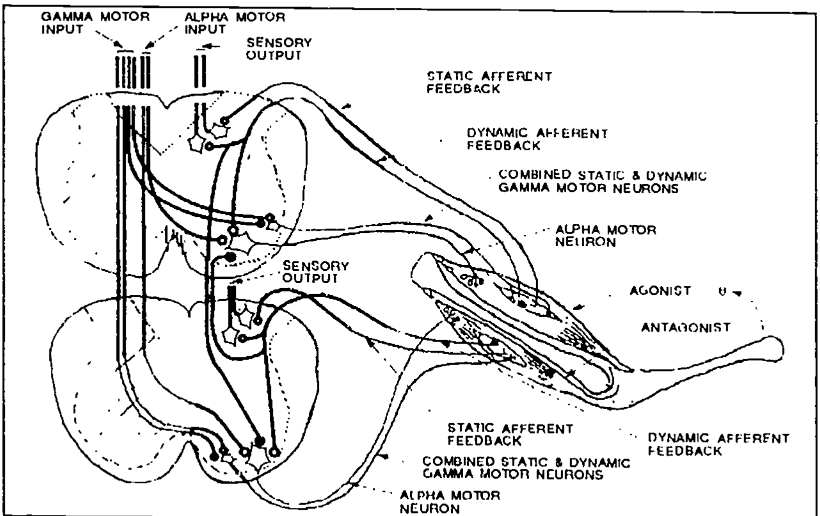


**Figure 1**
**Elbow Joint Anatomy & Physiology**

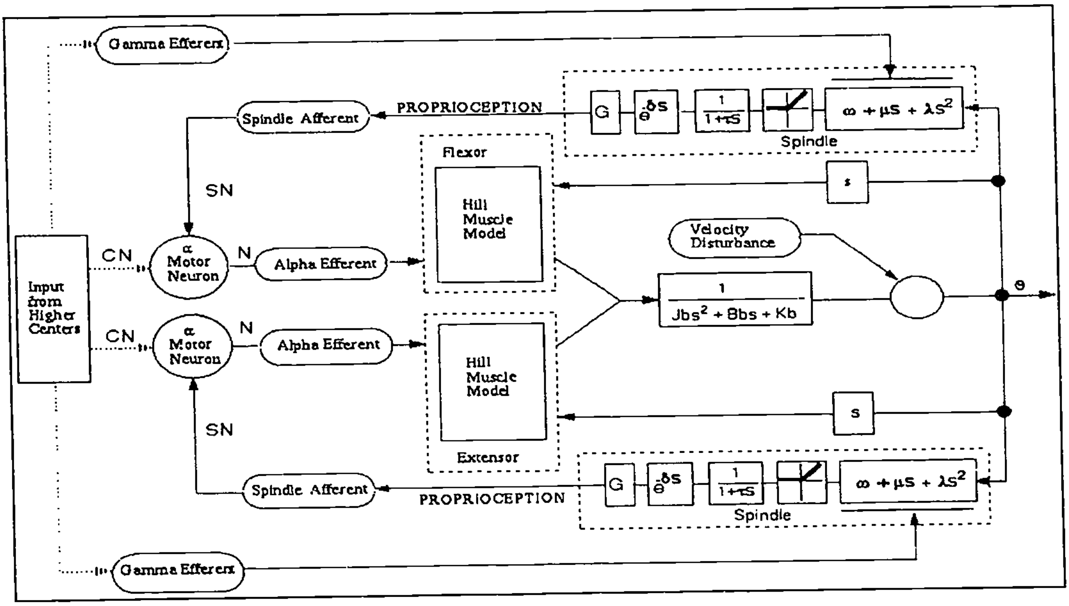


**Figure 2**
**Joint Angle Control System**

influence from higher centers acting as input to that system. The anatomical and physiological connections of one joint angle control system (the elbow) are illustrated schematically in Figure 1.

Several studies in neuromuscular control have been undertaken in recent years which are of interest in determining the effect of central nervous system influence at the spinal level. Ramos, et al.[7] have used a 6th order muscle and a 3rd order muscle spindle model to demonstrate the source of the triphasic EMG patterns seen in ballistic head movements. The Ramos[6] model of the joint angle control system is presented in Figure 2.

It is the intent of the present investigators to adapt an approach similar to Ramos and Stark[8] in examining the effect of the vestibular apparatus on the tone of those with cerebral palsy.

## PROBLEM STATEMENT

How might modern systems modeling be used to enhance the understanding of the effect of vestibular stimulation on the overall tone of those with cerebral palsy?

## APPROACH

In order to test the effects of vestibular stimulation on those with cerebral palsy a testing protocol has been developed which will measure the stiffness of the elbow or wrist joint before and after stimulation. A Joint Assessment Device (JAD), from Shriners Hospital in Chicago, will be used. This device, designed to apply a velocity across a joint while monitoring the torque required to maintain the velocity, has been tested and used extensively by Harris[5],[3],[4]. He has demonstrated its effectiveness in assessing changes in cerebral palsied patients before and after various interventions.

By applying the JAD before and after a subject is stimulated on our Vestibular Stimulation Table [1], recordings can be made of velocity, torque, and surface EMG from the muscles of the joint under test. While a difference in joint stiffness will be expected as a result of stimulation, it will not be clear from this data alone what mechanisms have caused this change.

Viewed in terms of input to the Joint Angle Control System, vestibular stimulation may act via the alpha or the gamma motor neurons. While the EMG signal can be expected to be proportional to alpha motor neuron excitation, the signals cannot distinguish between the origins of this excitation, i.e. direct excitation or by way of the dynamic afferents of the stretch reflex loop. Some of this ambiguity can be eliminated by examining the dynamics of a system model.

The Ramos model can be defined by 16 equations. Seven of these are given below and are of interest here. Starting with these equations the authors will solve for a profile of torque(output) given a step change in joint velocity (input). This will allow a direct comparison between modeled data and

$$\dot{V} = \frac{-Kp\theta - BpV + Fs_L - Fs_R}{Jp} = A \quad (1)$$

$$\dot{SN}_L = \frac{1}{\tau}(G(-\omega\theta - \mu V - \lambda A) - SN_L)) \quad \text{For } (\omega\theta + \mu V + \lambda A) < 0$$
$$= -SN_L/\tau \quad \text{Otherwise} \quad (2)$$

$$\dot{SN}_R = \frac{1}{\tau}(G(-\omega\theta - \mu V - \lambda A) - SN_R) \quad \text{For } (\omega\theta + \mu V + \lambda A) < 0$$
$$= -SN_R/\tau \quad \text{Otherwise} \quad (3)$$

$$SN'_L(t) = SN_L(t-\delta) \quad (4)$$
$$SN'_R(t) = SN_R(t-\delta) \quad (5)$$
$$N_L = CN_L + SN'_L \quad (6)$$
$$N_R = CN_R + SN'_R \quad (7)$$

Kp = Load Stiffness*
Bp = Load Dampening*
Jp = Load Inertia*
Fs = Muscle Force (R & L)
SN = Feedback from the Muscle Spindle (R & L)
$\omega$ = Position Feedback Weighting Function
$\mu$ = Velocity Feedback Weighting Function
$\lambda$ = Acceleration Feedback Weighting Function
CN = Central Nervous System input (R & L)
N = Alpha Motor Neuron Excitation (R & L)*

recorded data. Once this solution has been obtained, optimization techniques can be applied which permit the evaluation of various parameters.

Again, of interest is the route by which the vestibular apparatus effects tone. This effect can be mediated via four mechanisms: 1) changing alpha motor neuron excitation, 2) changing dynamic gamma motor neuron excitation, 3) changing static motor excitation, or 4) a combination of all three. In the Ramos model these mechanisms are represented by the following parameters:

$N_L$: Alpha motor neuron excitation
$\mu$: Dynamic gamma motor excitation
$\omega$: Static gamma motor excitation.

It should be pointed out that a fourth variable $\lambda$ (the acceleration weighting function) is used in the Ramos model to account for non-linearities in the spindle afferent information. This variable would appear to be dependent on both static and dynamic gamma excitation and changes in it would imply vestibular influence via the gamma route.

In applying Bremerman's Optimization Techniques, outlined by Ramos, et al.[7], one would use a cost function which would minimize the difference between the dynamics of the model and the actual recorded dynamics of the subjects. This would establish values for the three parameters outlined above. The same optimization, repeated for data collected after vestibular stimulation, should offer considerable insight into the way in which such stimulation influences tone.

*These variables will be available from the Joint Assessment Device

It must be noted that the three parameters defined above fall in two distinct groups. Alpha excitation comes from direct measurement of surface EMG, whereas static and dynamic gamma excitation will not be measured in the present work and thus will be calculated. Further, alpha excitation will be dependent on gamma excitation via the stretch reflex loop. This complication must be given careful consideration when any optimization is applied.

The experimental setup will be such that surface EMG will be presented to each subject on a CRT screen. At the outset of each experiment the subject will be instructed to make his EMG activity as small as possible. If the simulations runs using the model are then limited to the first 50 - 80 msec. (i.e. the time for a signal to arrive from the brain) it can be assumed that all activity in the EMG is due to feedback (stretch reflex loop) activity.

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James W. Fee, Jr.
Applied Science and Engineering Laboratories
Alfred I. duPont Institute
P. O. Box 269
Wilmington, DE 19899
Phone: (302)651-6830

# World Class Manufacturing, Ergonomic Intervention, and Implementation of the ADA

Don Malzahn, Ph.D
Industrial Engineering Department, Rehabilitation Engineering Center
Wichita State University, Wichita, KS

Monique Lanciault, M.S.I.E., Human Performance Analyst
Boeing Commercial Airplane Group, Wichita Division, Wichita, KS

## Abstract

The Americans with Disabilities Act was signed into law by President Bush on July 26, 1990. Title I of the act requires non-discrimination in employment, with reasonable accommodations for potential and current employees. According to Title I, employers, must make reasonable accommodations to the known physical or mental limitations of an otherwise qualified individual. A reasonable accommodation is an adaptation of the workplace, the equipment or the job itself which enables a disabled employee to perform the essential functions of a particular job. Ergonomists evaluate accommodations designed to reduce or eliminate ergonomic stressors in the workplace. Ergonomists are also qualified to evaluate reasonable accommodations of the workplace, its procedures and access for disabled employees. While industries are trying to comply with the ADA, they are in the process of a methods revolution in response to global competition.

## Background

The objective of ergonomics is to adapt the job and workplace to the worker by designing tasks within the worker's capabilities and limitations (OSHA, 1988). In essence, it is making reasonable accommodations for all workers, not specifically disabled workers.

American industry is currently in the midst of a revolution of its methods of operation. International competition has revealed operating inefficiencies and a lack of flexibility (Harmon, 1992; Schonberger, 1986). The restructuring of American industry is focusing on eliminating non-value added activities and shifting operational control to lower levels in the organization. These actions are requiring industry to closely examine each task's contribution to the value of the final product and develop more autonomous groups of functions and employees such as manufacturing cells and focused factories (Whyte, 1991; Osburn, et.al., 1990).

As industry has sought to meet demands for increased economic efficiency it has also realized significant losses due to repetitive motion disorders, primarily carpal tunnel syndrome and back injuries. Back injuries caused by overexertion have been calculated to cost industry over $3,000,000,000 in 1985 (Eby, 1991). The average costs associated with a carpal tunnel syndrome case have been estimated to be between $15,000 and $18,000 (Fernandez et al., 1990). The response of industry has been to initiate programs that examine task for the repetitive stressors involved and redesign the tasks in order to reduce the levels of exertion required for their accomplishment. Similar studies are being performed on cognitive tasks in order to reduce the cognitive load of information based tasks. These actions involve direct examination of the functional requirements of human tasks. The impact of chronic exposures to excessive stress are becoming apparent in the nondisabled population thus increasing the number of persons with disabilities (Pope, 1991). Many larger firms are establishing ergonomics programs in order to reduce the incidence of work related injuries and increase quality and productivity (Katzel, 1991).

Many firms are attempting to retain their workers after an injury has occurred. They are finding it more cost effective to retain a worker than hiring a replacement. Many employees who leave because of an injury could be put back to work almost immediately if provided a reasonable accommodation or if reassigned to a task that fits their capabilities. It is here that job descriptions of essential job functions will be a valuable tool to return people to work.

## Statement of the Problem

The current interest shown in eliminating non-value added activities has spurred the implementation of a variety of new management techniques such as; just-in-time, demand pull production, cellular manufacturing, and activity based accounting. Businesses must be able to determine which of the activities normally performed during a task are in fact "essential functions". The definition of "essential functions" requires a systematic determination of the basic business processes. A major reason for the trauma being experience by industry in adopting these new techniques is that management practices have developed in a piecemeal fashion by responding to each new requirement with a more complex system. This evolutionary process frequently has developed system that do not respond to overall organizational objectives. These same process have had an impact on task design. Tasks have evolved in response to the demands of production with little formal regard to the capabilities of the workforce. Most jobs are not designed on sound ergonomic principles

Qualified Individual with a Disability. A "qualified individual with a disability" refers to an individual "who with or without reasonable accommodation, can perform the essential functions of the employment position that such individual holds or desires" (442 US SCt 403, 406 (1979)).

Reasonable Accommodation. Discrimination includes the failure to make "reasonable accommodations to the known physical or mental limitations of an otherwise qualified individual with a disability who is an applicant or employee," (42 U.S.C. # 1211(b)(1) and (b)(5)(a)).

Determining the appropriate reasonable accommodation is described by the EEOC as:

"(1) Analyze the particular job involved and determine its purpose and essential functions;

(2) Consult with the person with a disability to ascertain the precise job-related limitations imposed by the individual's disability and how those limitations could be overcome with a reasonable accommodation;
(3) In the consultation with the individual to be accommodated, identify potential accommodations and assess the effectiveness each would have in enabling the individual to perform the essential functions of the position; and
(4) Consider the preference of the individual to be accommodated and select and implement that accommodation that is most appropriate for both the employee and employer."

Undue Hardship. Undue hardship is defined by the EEOC in the Appendix to the ADA regulations as "any accommodation that would be unduly costly, expensive, substantial, or disruptive, or that would fundamentally alter the nature or the operation of the business" (42 U.S.C. # 1211(10)(A)). Factors to be considered in determining undue hardship include:

1. the nature and cost of the accommodation;
2. the overall financial resources of the facility;
3. the number of persons employed;
4. the effect of the accommodation on facility operation; and
5. the type of operation.

An employer will be required to provide the accommodation, even if it cannot afford to do so, if funds are available from another source (such as Vocational Rehabilitation Services), or the disabled employee is in a position to either provide the accommodation himself or pay "that portion of the cost which constitutes the undue hardship" (Appendix to 29 CFR Part 1630, 56 Fed. Reg. at 35748).

Undue hardship may also come in the form of lost efficiency such as in the situation where accommodations made by an employer were reasonable and affordable, but the performance of by the individual with a disability was significantly lower than that of other workers in the same position.

Essential Job Functions The determination of which portions of a job are nonessential and therefore not relevant to the employee selection process requires careful analysis. In the case of Koffler v. Hahnemann University the court found that although functions requiring less than 10 percent of the working time could not be performed because of a disability, these functions were essential components of the position. It stated that "to require an employer to adopt an entirely different standard of attendance for a handicapped person is not a reasonable accommodation as a matter of law. The handicapped individual must be able to perform all of his responsibilities after reasonable accommodation".

A primary source for determining "essential job functions" is a written job description developed before advertising or interviewing for the position. There currently exists no standard for developing "functional" job descriptions. In fact, many firms are in the process of revising job description so that they are less specific. This is part of industry's attempt to increase efficiency through developing a more flexible and responsive system of labor specifications. Each employee may be asked to perform a wide variety of tasks and functions can be changed unpredictably. The lack of detail in these new forms of job descriptions may make it easier to "qualify" for a job, but it may also make it more difficult to define "essential job functions". Determining essential job functions will be tasks that the ergonomists can perform.

## Implications

Factors Supporting ADA Implementation

1. Definition of value adding activities and "essential functions"
2. Emphasis on human capability and task design (ergonomics)
3. Focus on work teams which allow employees within teams to share task responsibilities
4. Direct intervention of ergonomists in task design
5. Many "accommodations" become standard parts of the task as performed by all employees
6. Requirement through workmen's compensation that funds vocational rehabilitation, many firms will find it more cost effective to accommodate task to the injured worker than to hire and train a new worker
7. Increasing role of "participatory ergonomics" in task design

Factors Conflicting with ADA Implementation

1. Less specific job descriptions
2. Greater skill variety expected for each position in the workforce
3. Movement away from individual performance standards (piece rates) to group and skill based systems
4. Many industries are making major changes in their operations and may be reluctant to make the additional changes required by the ADA
5. No increase in Vocational Rehabilitation funding to reduce "undue hardship" on firms

## Discussion

The result of the latest Harris survey commissioned by the

National Organization on Disability, "Public Attitudes Toward People with Disabilities," reveals significant support for the objectives of the ADA. Although fewer than 1 in 5 had heard of the ADA, two-thirds believes that disabled people are "discriminated against in equal access to employment", a third advocates spending "a great deal" of money to make schools, transportation and public facilities more accessible, and 80 percent believe disabled people want to work.

Since the law was signed in 1990, there has been a huge public investment in ADA education. Thus far the federal government has awarded over $12,000,000 in grants and contracts to provide education and training materials. There has been no increase in the EEOC budget for enforcement or significant investment in developing the technical expertise to interpret and implement the ADA requirements at the individual accommodation level.

Most of the effort spent in refining job descriptions and requirements will be returned through better job design and reduction of non-value added activities.

There are numerous examples of systems developed for persons with disabilities that have been incorporated into systems widely used in industry by the general population. Each of these systems was designed to augment a specific disability. This augmentation often also reduces the stress experienced by persons without disabilities when performing tasks. The graphical user interface (GUI) that is becoming popular for computer systems is an application of symbolic communication that has a long history in the form of Bliss symbols. Recent interest in workplace seating has brought about the development of "ergonomic" neutral posture seating systems. The design of positioning systems is another area which has been pioneered in application to persons with disabilities. Modern hand tools bare a remarkable resemblance to eating utensils designed for persons with limited grip strength and dexterity. Reducing the stress produced by a task through design make the task accessible to a larger population.

Who does the modification belong to. If it is funded by vocational rehabilitation, can it be used by others. What impact will this have for the severely disabled? Will the standard for reasonable accommodation change over time? Are there sufficient resources available for rationale task design and modification? Given the current demand for qualified ergonomists, there is a shortage. Skill required in both rehabilitation and production systems.

Acknowledgements

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Don Malzahn
Industrial Engineering Department
Wichita State University
Wichita KS 67208

2.1

# A Neuroprosthetic Cough Assist Device for use in Spinal Cord Injury

RJ Jaeger[1,2] J Woloszko [1] RM Turba[2] GM Yarkony[2,1] EJ Roth[2]
[1]Pritzker Inst Med Eng, Illinois Inst Tech, Chicago, IL USA
[2]Dept Rehab Med, Northwestern Univ, Chicago, IL USA

## Introduction

This research focuses on using electrical stimulation in an application that might have great impact on improving the life span of individuals with higher level spinal cord injuries. Pulmonary complications are now recognized as a major contributor to mortality in these individuals, presently accounting for the majority of morbidity and mortality of spinal cord injuries. Retention of secretions, atelectasis, and pneumonia are the most commonly occurring complications. Loss of the ability to cough is at least a partial (if not a major) contributor to these pulmonary complications. A prototype neural prosthetic device is described that can improve the ability of individuals to cough.

## Methods

Inability to cough is primarily due to paralysis of abdominal muscles which are the major muscles of expiration. These muscles are amenable to electrical stimulation with surface electrodes. The proposed device for cough assist should not be confused with existing devices for phrenic pacing. Phrenic pacing is intended to cause contraction of the diaphragm, the major muscle of inspiration.

A prototype neuroprosthetic device has been developed to allow a quadriplegic individual with impaired cough to voluntarily produce electrically stimulated coughs without immediate assistance of a care giver. The device measures 13x8.5 x4.5 cm, and weighs 435 g. It is similar to a previous stimulator developed for lower-extremity applications. It is microprocessor controlled (Intel 87C51). Power is provided by 4 AA cells, and stimulus pulses are generated with pulse transformers.

Surface electrodes (Encore™ Plus, round 7.6 cm diameter) deliver stimulation to abdominal muscles. Two pairs of electrodes are used. They are placed as shown in figure 1. The stimulator delivers a single pulse train of adjustable duration (0.5 to 2.0 s). Individual pulses are 200us wide, delivered at a 50 Hz stimulation frequency. The amplitude is adjustable between 0 and 110 V. The stimulator is triggered by pressing the command switch. The unit beeps, then delivers the pulse train to abdominal muscles to initiate the cough. The user is responsible for coordinating the breathing pattern prior to the cough (a good inspiration is needed) and the holding and release of the glottis.

## Results

Ten quadriplegic patients were enrolled in a study to test the effectiveness of this technique. Peak expiratory flow was measured ("Assess" flow meter, Healthscan Products) during voluntary, manually assisted, and electrically stimulated coughs. Acceptable abdominal muscle contractions were obtained in five of the ten patients. Sensation to the stimulation precluded use of the technique in four patients, and atrophied abdominal muscles appeared to be a problem in two patients. The three types of coughs were alternately measured (e.g. voluntary with no manual assist, manually assisted, electrically stimulated) for five repetitions. Thus a total of 15 cough measurements were made on each subject. Data from subjects with abdominal muscles that responded to stimulation were analyzed with an analysis of variance, after normalizing flows to the mean flow for volitional coughs. The normalization was done on an individual basis. The mean peak flow of the volitional cough was computed by averaging the 5 repetitions of the volitional cough (no assist). Then, every cough measurement for that patient was divided by this mean. In this way, all subjects had a volitional cough index of 1.0. If peak flows were better than volitional, the index had a value of greater than 1.0. There was a significant difference between the three types of cough, and post hoc comparisons found the means of normalized data for all three groups to differ. The normalized data is summarized in figure 2.

**Discussion**

Pulmonary complications represent multifaceted problem, and it is not likely that a single solution will completely solve the problem. Therefore, a variety of approaches to different aspects of this problem have been proposed. For example, ventilation has been achieved by both mechanical ventilation and by phrenic pacing. This device is directed to the problem of clearing secretions from the respiratory passageways. In higher level spinal cord injury the patient is impaired in the ability to clear secretions. This has been dealt with primarily by passive drainage (positioning the patient so drainage occurs by gravity), active suction (if secretions are particularly heavy), and assisted or "quad" cough (manual pressure applied to the abdomen by a therapist). Each of these methods have varying degrees of effectiveness, however they all require active intervention by a care giver. Studies have shown that a significant improvement in cough can be achieved by the manually assisted method. This method has the obvious advantage of providing a cough when no cough (or a poor cough) could be generated by the individual. It has the disadvantage of requiring an assistant every time a cough is to be produced. Given the eventual compromises that are made with respect to medical care, it is highly likely that patients do not cough with the frequency they should. No definitive study can be cited to support this supposition. At present, there is at least some indirect support for this supposition, since increased pulmonary complications are present in this population, and clinical attempts have been made to restore some type of cough activity via the assisted cough.

In general, neural prosthetic devices targeting relatively few muscles with minimal channels of stimulation, and open loop control requirements have been the most successful and most likely to impact increasing the life span of persons with spinal cord injury. This is typified by devices for bladder control and phrenic pacing. Based on this line of reasoning, the technique proposed in this project is also likely to be successful. This is not to say however, that there are no problems to be overcome in the proposed approach. Anticipated problems with the proposed research include training individuals to coordinate their volitional activity to work in concert with the stimulator, sensitivity to the electrical stimulation in incomplete individual, possible effects on bowel and bladder programs, and the need for an alarm system in cases where suction would be required. If clinical feasibility can be demonstrated, long-term studies would be needed to quantify the efficacy of such an approach in reducing the incidence of respiratory complications. Independence from care givers is a hallmark of effective rehabilitation in nearly every case. The long-term goal of this research is to make individuals independent of a care giver with respect to cough.

**Acknowledgements**

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**Address**

Robert J. Jaeger
Pritzker Inst Medical Engineering
Illinois Institute of Technology
10 West 32nd Street, E1-125
Chicago, IL 60616

Figure 1: Schematic illustration of electrode placement.

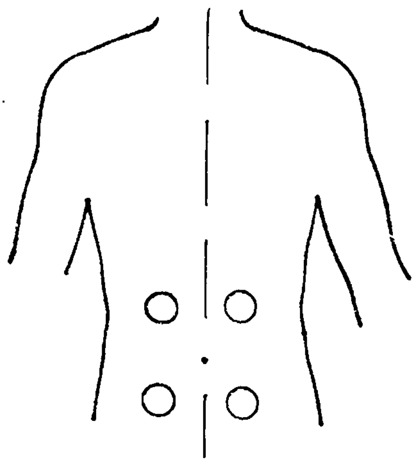
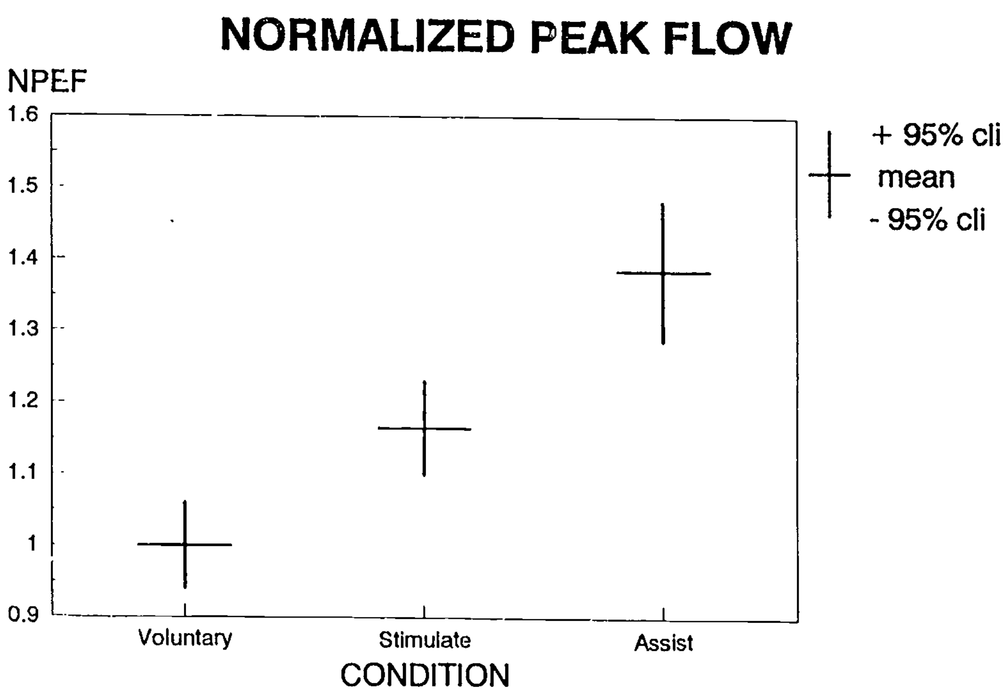


Figure 2: Comparison of three cough methods, voluntary, electrical stimulation, and assisted. Means ± 95% confidence intervals are plotted. Coughs have all been normalized to voluntary cough (e.g. data were transformed (individual observation of peak expiratory flow)/(mean peak expiratory flow for voluntary coughs). See text for details.



# Surgical Alterations and Functional Electrical Stimulation for Restoration of Hand Function

P. Hunter Peckham, Michael W. Keith, Kevin L. Kilgore, Kathryn C. Stroh, Ronald L. Hart

Case Western Reserve University
Veterans Affairs Medical Center
Rehabilitation Engineering Center
Cleveland, Ohio 44106

Functional electrical stimulation (FES) has been shown to be an effective method to restore hand function and improve the capabilities for independent function of ADL tasks (Wijman, 1990). In some instances, we have found that the use of tendon transfers of paralyzed and innervated muscles, combined with electrical stimulation, can be used to improve function. The objectives of this approach are: 1) to substitute for muscles which are denervated and cannot be electrically excited, 2) to reduce the number of joints that are moved ("motored") by the muscle, and 3) to provide more synchronous joint movement and force transmission.

Methods and Subjects. Subjects for this procedure were nine individuals who had sustained spinal cord injury and had remaining C5 or C6 level injury. All patients were users of an upper extremity FES neuroprosthesis and were at least one year post-injury. The surgical procedures performed include arthrodeses, tendon transfers, tendon anastomoses, and rotational osteotomy. These procedures were commonly applied hand surgical procedures which were tailored to the individual dysfunction of each patient.

Results. The specific procedures are shown in Table 1. Note that a variety of procedures were performed, and that generally several procedures were performed on any individual patient. The most common procedures were fusion of the interphalangeal joint of the thumb, synchronization of finger flexor and/or extensor tendons, and tendon transfers to substitute for a denervated muscle. Tendon transfers were most variable because the muscle being transferred must be both electrically excitable and transferrable for the desired function. The latter consideration means having sufficient strength and excursion for the new function, a direct line of pull after transfer, and absence of secondary movements.

Table 1. Surgical Alterations

| | SUBJECT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PROCEDURE | GP | VG | JJ | KT | PO | AK | NM | JM | RZ |
| Flexor Synchronization | √ | √ | √ | √ | √ | | √ | √ | √ |
| Extensor Synchronization | | √ | √ | √ | | | √ | | |
| Thumb Interphalangeal Arthrodesis | √ | √ | √ | | √ | √ | | | √ |
| Tendon Transfer and Stimulation of UMNL* Muscle | √ | | √ | √ | | | √ | | √ |
| Zancolli Lasso | | | √ | √ | | | | | |
| Rotational Osteotomy | | | | | √ | | √ | | |

* Upper Motor Neuron Lesion

We have used force vectors as a means of predicting the utility of any particular muscle as a transfer. An example is shown in Fig. 1. The subject of this study was KHT, a C5 quadriplegic man, who had no voluntarily active wrist extensors and denervated extensor carpi radialis longus and brevis. Since KHT wanted to be free of an orthosis for wrist stabilization, we examined two muscles for transfer: the flexor carpi radialis (FCR) and extensor carpi ulnaris (ECU), both voluntarily inactive but electrically excitable muscles. As shown in this figure, both muscles generated substantial wrist moments, with the FCR approximately three times stronger than the ECU. However, the ECU was selected for transfer because we estimated that it was sufficiently strong and had a forearm moment towards supination that would reinforce the rather weak voluntary supination generated by Biceps. The FCR, in contrast, would generate pronation. The result of the transfer of ECU to ECRB is also shown in the figure. Wrist extension generated by the transferred and stimulated ECU is nearly in direct extension, until spillover to an adjacent muscle occurs. This wrist extension has been sufficient to free KHT of his wrist-hand orthosis in outpatient use.

We have found that the transfers of paralyzed muscles are subject to the same complications as normal muscles (eg. tendon rupture, adhesions), and that transfers can upset the balance between muscles in the hand. To minimize these potential problems, we have used intraoperative electrical stimulation to assess the proper balance between muscles (Mendelson et.al. 1988; Freehafer et.al. 1988) and early mobilization of muscles post-surgery, using electrical stimulation to provide controlled activation of antagonistic muscles in alternating lengthening and shortening sequences. These procedures have been transferred to our collaborating center at Shriners Hospital in Philadelphia, which has performed similar procedures in four patients.

Conclusions. Surgical alterations are an effective means to compliment FES in restoring function in the hand. Proper selection of muscles and transfers can be based on standard hand surgery principles. Precautions to promote optimal function include intra-operative stimulation and post-operative mobilization using FES.

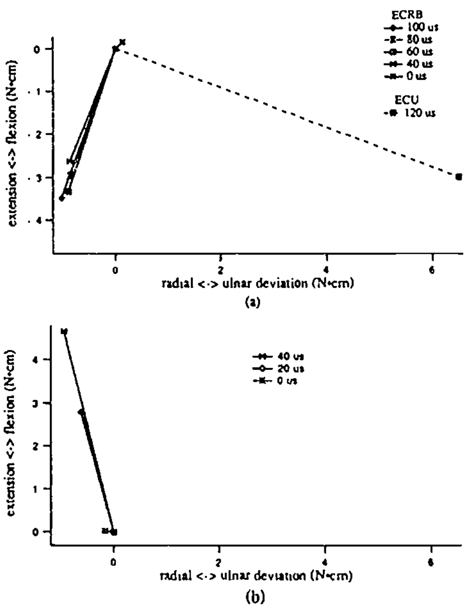



Figure 1. Wrist torques developed by electrically stimulated muscles. (a) ECU before and after transfer to ECRB, and (b) FCR

Acknowledgements. The authors acknowledge the support of the Neural Prosthesis Program Contract No. NIH-N01-NS-9-2356 and the Veterans Affairs Rehabilitation Research and Development Service for support of this research.

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P. Hunter Peckham, Ph.D.
Rehabilitation Engineering Center
MetroHealth Medical Center
2500 MetroHealth Drive
Cleveland, Ohio 44109-1998

# A NEURAL NETWORK-VOICE CONTROLLED NEUROMUSCULAR ELECTRICAL STIMULATION SYSTEM FOR TETRAPLEGICS

Alberto Cliquet Jr , André Mendeleck, Dérlis R.F. Quesnel,
François X. Sovi, Paulo Felipe Jr., Telma D. Oberg,
Gleiser J P Lemos, Elcio A. Guimarães & Antonio A.F. Quevedo
Dept of Biomedical Engineering, Fac of Electrical Engineering
State University of Campinas, Campinas, SP, Brazil

## ABSTRACT

This paper presents the development and feasibility study of a system for restoration of upper limb movement to tetraplegics, through a neuromuscular stimulation voice controlled system and using artificial neural networks. The system is composed of several modules which are responsible for the filtering and sampling of voice, digital signal processing, pattern recognition and neuromuscular stimulation. The pattern recognition module, to identify the phonemes, was implemented using a neural network paradigm, employing a multilayer Perceptron neural network with Backpropagation training method. Neural networks were chosen because they allow a massive parallelism, high processing speed, and capacity of adaptation for new sonorous patterns

## BACKGROUND

Restoration of upper limb functions to cervical lesioned subjects through electrical stimulation has been under investigation Multichannel stimulators allow a large number of movements to the paralysed limb (1). Complete tetraplegics show extra difficulties in the selection of hand-wrist, arm and forearm movements, since the way to triggering the stimulation will depend on the patient's remained physical abilities The latter aspect leads to a specific data input system for a particular patient. Taking into account that most of these patients have their voices preserved, a voice controlled stimulator can become a modular and functional rehabilitation system

## STATEMENT OF THE PROBLEM

The aim of this work was to develop a Neuromuscular Electrical Stimulator for Tetraplegics based upon a Voice Control System

The voice commanding input system must be reliable and able to easily adapt to different sound patterns inherent to different subjects (new users), i.e. without the need for a complex training for each individual.

## RATIONALE

Despite the fact that Neuromuscular Electrical Stimulation can be done through several control strategies, a Voice Controlled System seems to be more suitable to tetraplegics with different level of lesions (complete or incomplete) In order to have an effective voice pattern recognition system, Artificial Neural Networks were used because they adapt to deviations on sound patterns, both within the same patient and with different subjects.

## DESIGN

The system is composed of five modules which are responsible for filtering and sampling sonorous signals, signal processing, pattern recognition and neuromuscular stimulation.

A low pass filter (1 KHz) was used for the spectral analysis. The sampling made use of an A/D converter (2 KHz), yielding a vector with 1024 time signal samples. A FFT module generated an 1 KHz normalised spectrum. This spectrum was subdivided into 10 equal bands, each with 100 Hz, from which higher energy frequencies were selected.

Sound pattern recognition was implemented on the neural network module, through the use of a multilayer Perceptron neural network with Backpropagation training methodology. The network relies on 10 inputs, 3 layers with 30 neurons each and the outputs responsible for the neuromuscular groups to be activated through stimulation

## DEVELOPMENT

From observations on vowel time signals (/a/, /e/, /i/, /o/ and /u/) of our language system, periodicity and very little amplitude changes were noticed: in the frequency spectrum, these phonemes do show distinct and well defined patterns. Furthermore, when sampling the signal within the same patient, at regular intervals (hours and days), the frequency spectrum varies little, despite amplitude changes in the enveloping. The phonemes /a/, /e/ and /i/ were chosen in order to activate the paralysed arm of a C-6 incomplete tetraplegic (3 channels were enough for such subject).

The neural network implemented is the multilayer type Perceptron with backpropagation training method. This network works as a classifier, where the neurones perform a weighing job with their input values being associated to synaptic weights. The first layer is a Perceptron network receiving the input values directly. A synaptic connection between inputs and neurones and between neurones is performed through a synaptic connection weight.

Training a network consists in determining the synaptic connections in such a way that once a learned pattern is presented at the input, the network yields the desired values at the outputs.

The training was performed using three patterns (phonemes) one for each neuromuscular group to be activated: /a/, /e/ e /i/ and 5 samples of 3 male patients. The samples were taken in different days, increasing the variability to the patterns and therefore making sure that the network would be less susceptible to noise due to changes in the sound patterns.

The patterns were generated at random. About 70000 iterations were made with 14 CPU hours and a maximum error of + 0.01 in the input values. The system was developed in a SUN workstation

## EVALUATION AND DISCUSSION

The system was implemented in an IBM-PC microcomputer, being tested on an incomplete C6 tetraplegic. With phonemes from male patients, the network showed an index of success of about 70%; with female voices (5 subjects), this rate was bellow 20%, yielding output values different from the expected ones.

.he prototype was tested and a good acceptance of the system by the patient (C6) was noticed, for with a single voice command, he could control his arm movement. Further clinical tests are being done in order to optimize the system.

## ACKNOWLEGEMENTS

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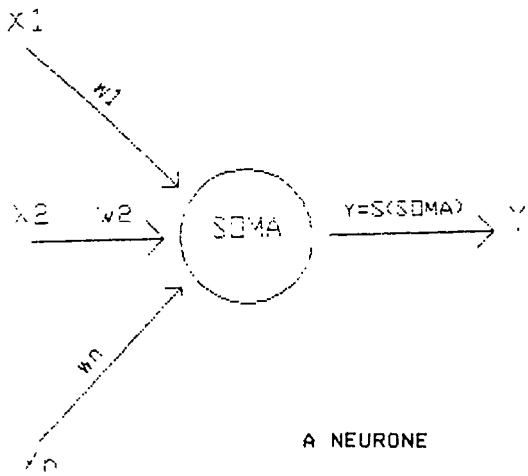
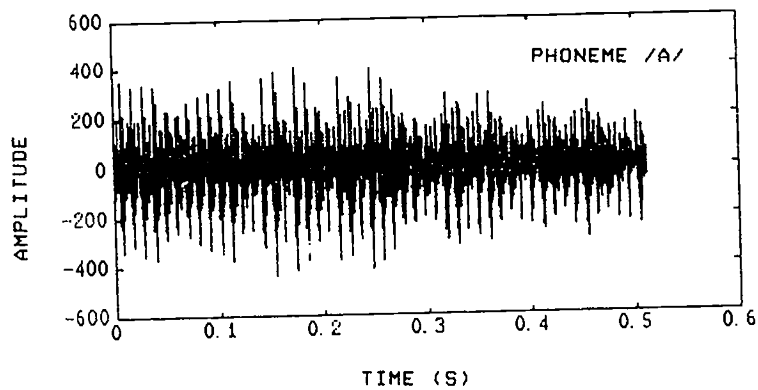
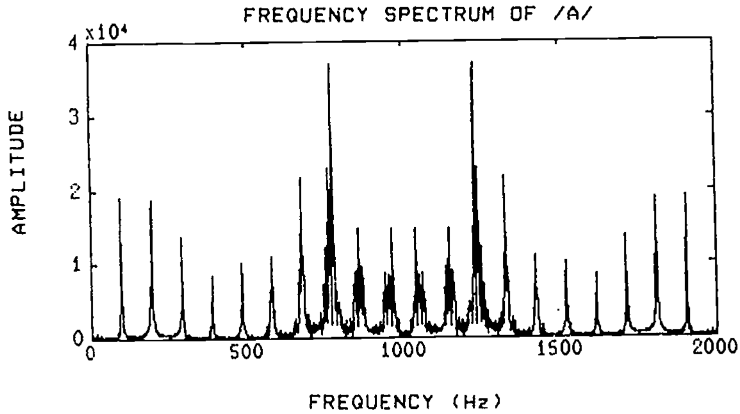
Prof. Dr. A. Cliquet Jr.
Dept. Eng. Biomédica / Unicamp
C.P. 6040
13081 Campinas SP Brasil


X1
W2
Y=S(SOMA)

A NEURONE


PHONEME /A/
AMPLITUDE
600
400
200
0
-200
-400
-600
0
0.1
0.2
0.3
0.4
0.5
0.6
TIME (S)


FREQUENCY SPECTRUM OF /A/
x10⁴
AMPLITUDE
4
3
2
1
0
0
500
1000
1500
2000
FREQUENCY (Hz)

2.4

# AN UPPER BODY EXERCISE SYSTEM INCORPORATING RESISTIVE EXERCISE WITH ELECTROMYOGRAPHIC FEEDBACK

T. Cameron, MS[1], L.E. Peppard, PhD[1], B. Needham-Shropshire, OTR[2], J. Broton, PhD[2], and K.J. Klose, PhD[2]
[1]Queen's University, Dept. of Electrical Engineering, Kingston ONT;
[2]The Miami Project, University of Miami, Dept. of Neurological Surgery, Miami FL.

## ABSTRACT

As a concequence of spinal cord injury (SCI) neurological impulses between the brain and the periphery are disrupted. Quadriplegia results when this disruption occurs in the cervical region of the spinal cord . These individuals are usually confined to a wheelchair and have variable degrees of function in the upper extremities. A common mode of therapy used in the rehabilitation of cervical spinal cord injured (CSCI) individuals is resistive training (1,2). Muscle strengthening can not only increase function but also contributes to a better self image. Traditional training, involving weights and ergometric cycling, can increase the overall strength of the patient but does not target the more severely compromised muscles. We have found that more effective training can occur when the patient can see electromyographic (EMG) signals produced by individual muscles. We have developed a system that incorporates resistive training with EMG feedback, thus allowing the individual to modify the EMG activity of individual muscles during the exercise program. The system has been tested with normal subjects and is now undergoing clinical trials with a group of CSCI individuals.

## BACKGROUND

Spinal cord injury afflicts nearly half a million people in the United States, with approximately 10,000 new cases occurring each year (2). The majority of injuries occur in young (16-30) healthy individuals, and are four times as likely to be male than female (3). Injuries to the cervical region of the spinal cord account for approximately 53% of all those with spinal cord injuries and 30% of these injuries are incomplete (3). A majority of these injuries occur at the C5-C6 level due to the cervical enlargement of the spinal cord . When an incomplete lesion occurs the patient may be left with partially innervated muscles. A typical patient may have normally innervated biceps (C5) but only partially innerverated triceps (C6-C7)(5). With proper therapy patients can recover some function within the first few years of injury; however, additional recovery can be very slow. This can be attributed to muscle atrophy and lack of sensation. A muscle that is not used is known to atrophy (4,5,6), and in spinal cord injured patients a muscle can atrophy to the point where no observable twitch is seen. Along with loss of strength of the muscle, important sensory feedback is also lost (5,6). This results in the loss of appropriate sensations needed to accompany muscle strengthening programs

Physical rehabilitation of CSCI individuals focuses mainly on upper body strengthening. A common device used for this purpose is an upper body ergometer. A patient is routinely set up on this device by an occupational therapist and then permitted to exercise. This type of exercise is effective in increasing strength in some muscles; however, stronger functioning muscles may compensate for weakened muscles, and the overall effectiveness of the exercise may be reduced. CSCI patients have both motor and sensory impairment and therefore lack normal proprioceptive feedback. This results in difficulty in determining the extent to which each muscle is contributing to the exercise. We have developed an exercise system that provides feedback to the individual based on electromyographic (EMG) signals from the involved muscles. These signals are presented to indicate to the patient and therapist the amount of individual muscle involvement during exercise.

## STATEMENT OF THE PROBLEM

The aim of this project was to develop an upper body exercise system that incorporates resistive exercise with electromyographic feedback.

## DESIGN

The system consists of an upper body ergometer (Saratoga Cycle) and a Myoview[1] EMG processing/display unit. Surface EMG is recorded and used to light a light emitting diode (LED) display in the unit. The EMG signal is differentially recorded via three surface electrodes (SensorMedics, 265-083547-D) placed over the muscle of interest. This signal is then sent to the Myoview control unit which amplifies, full-wave rectifies, and filters the signal. The control unit is capable of processing EMG signals from four different muscles simultaneously. Once processed the signal is displayed by colour coded LED arrays which act as "bar graphs" of muscle activity. This real-time display of muscle force is used by the patient during the exercise program to facilitate appropriate muscle involvement of weakened muscles while relaxing undesirable muscle activity. A block diagram of the overall system is shown in figure 1.

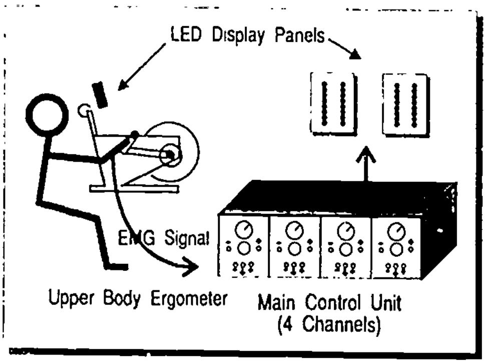



Figure 1: Block diagram of the exercise system showing the upper body ergometer, the main control unit and the LED display panels

## EVALUATION

This system has been tested on normally innervated subjects. The result of one such experiment is shown in figure 2. In this experiment the subject was told to exercise normally for several minutes while EMG signals were recorded from biceps and triceps on both arms. Figure 2a shows the EMG signal from the right triceps muscle without feedback during 3 cycles with the ergometer. The subject was then asked to exercise while watching the display in order to trying to use the triceps muscles more. Figure 2b shows the EMG signal from the right triceps muscle with feedback. It can be seen that when the subject was allowed to watch the LED display he was able to double the EMG output.

## DISCUSSION

We found that when the subject was able to monitor the EMG display during exercise, the EMG output of the muscle could be doubled. From these results we can conclude that this exercise system will be beneficial in the rehabilitation of spinal cord injured individuals. These individuals usually have difficulties targeting individual muscles because of their lack of proprioceptive feedback. By incorporating this system with an exercise program including electrical stimulation it may be possible to increase function of these individuals. Experiments with CSCI individuals are being conducted at the present time.

## ACKNOWLEDGMENTS

This project was funded by the Rick Hansen Man in Motion Legacy Foundation and NSERC operating grant #0000111.

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Tracy Cameron
23 Nelson St. #1
Kingston , ONT.
Canada
K7L 3W6

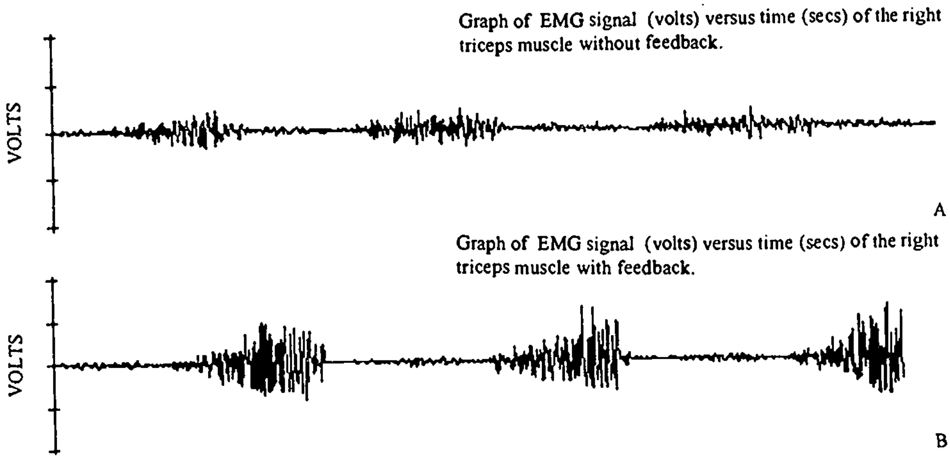


Figure 2: (A) This graph shows the EMG output of the right triceps muscle during three cycles of exercise without feedback. (B) This graph shows the EMG of the right triceps muscle during three cycles of exercise with feedback. Both traces last for a total of four secs and each tick on the y axis represents 4 volts.

2.5

# Technology Transfer of a Functional Electrical Stimulation Hand System

G.B. Thrope, G.G. Napies, R.G. Hart, K.C. Stroh, J.R. Buckett, A.R. Ignagni, M.W. Keith, P.H. Peckham, C.L. Van Doren
CWRU Rehabilitation Engineering Center Cleveland, OH

## Introduction

The Case Western Reserve University (CWRU) Rehabilitation Engineering Center has successfully completed a transfer of its neuroprosthetic hand system to four clinical centers in North America. The neuroprosthetic hand system enables quadriplegic Spinal Cord Injury (SCI) individuals to independently control the opening and closing of their hand through the application of functional electrical stimulation (FES) to their paralyzed muscles. The CWRU program had previously documented that twenty three SCI individuals realized a significant enhancement in their activities of daily living while using the hand system (Wijman, 1990). We had demonstrated that by using percutaneous electrodes, a cable electrode interface suitable to the user, a controller that was fairly simple to operate, and a stimulator / controller device that could be attached to the persons wheelchair, a person who previously had no volitional control of their hand could once again perform rudimentary yet important activities of daily living.

## Discussion

After proving that our systems were efficacious, we set out to transfer the identical research system to clinical sites to determine if similar results could be achieved with patients outside of Cleveland. Our hypothesis stated that the application of a neuroprosthetic hand system to people with a complete C5 or C6 SCI would enable the user to achieve greater independence, execute tasks more efficiently, and perform activities which he typically could not do without assistance. We chose clinical centers and investigators with strong backgrounds in rehabilitation engineering and medicine who would be able to be trained in the techniques of implementation and have the ability to collect evaluation data. At present, we have accomplished nearly all our goals, having 13 users implemented outside of Cleveland with our FES hand system.

There have been five phases to our program. The first phase encompassed the organization of our laboratory device into a clinically transferrable system, ensuring that we could not only train others in the implementation and evaluation of our system, but also provide documentation, workshop seminars, follow-up communication mechanisms, maintenance and service, and appropriate guidance in monitoring the study. Phase two consisted of choosing clinical collaborators and training them at a formal workshop. The clinical centers we chose were Rancho Los Amigos Rehabilitation Medical Center, (Los Angeles, California), Shriners Hospital for Crippled Children (Philadelphia, Pennsylvania), University of Alberta (Edmonton, Alberta, Canada), University of Toronto / Hugh McMillan Rehabilitation Centre (Toronto, Ontario, Canada). During phase three, the clinical centers were instructed to recruit, select, and implement systems with the SCI individuals. Once the subjects were competent users of the hand system, phase four would begin during which a thorough set of functional evaluations would be performed. We targeted a total of twelve users that we knew we could sustain in the program. At the conclusion of phase four, we would gather all the clinical data and analyze the results, which would complete the final phase of the study. We are currently retrieving the functional evaluation data on the 13 individuals who have been implemented with the hand system. All individuals were able to achieve a hand grasp with the system and each of them, with the exception of one person (out of protocol for our selection criteria) has found the system to be a useful, necessary device which facilitates tasks that are important for them to perform.

During the course of our investigation, we have had several inquiries into how to gain further access to our FES hand systems. All the clinical centers have made specific requests for additional systems. All the clinical centers have indicated that they would want to encourage their patients to pursue a completely implantable system once it became available. In addition, other programs worldwide such as The Robert Jones & Agnes Hunt Orthopaedic Hospital in Oswestry, England and the Austin Hospital (Heidelberg Victoria, Australia) are now actively pursuing funding to participate in a next stage technology transfer program which will use implantable stimulation technology and transition the existing system from a clinical research device to a clinician based unit (Smith, 1987).

**Conclusion**

In conclusion, we have not only witnessed positive results at clinical centers similar to our own in Cleveland, but have also been encouraged by users and clinicians to actively pursue the next stage of the hand system, which incorporates surgical reconstruction of the hand and permanent implantable radio frequency controlled systems. Since results to date in Cleveland are extremely encouraging with people who have implantable FES systems, we plan to build upon our first successful technology transfer program (Keith, 1988). Our approach will be to move our system towards being a final product to be transferred to a manufacturer for widespread distribution in our health care delivery system - which is the ultimate goal of a mature technology transfer project.

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Geoffrey Thrope
Rehabilitation Engineering Center
MetroHealth Medical Center
3395 Scranton Road
Cleveland OH 44109

2.6

# ENHANCEMENT OF THE HEALING STRENGTH OF ELECTRICALLY STIMULATED PRESSURE SORE WOUNDS

H.E. Kambic, T. Manning, E. Reyes, A. Hyodo & S.I. Reger
Department of Biomedical Engineering & Applied Therapeutics
The Cleveland Clinic Foundation; Cleveland, Ohio USA

## Introduction

Naturally occurring electrical fields in the body are important for growth, remodeling and repair. Electrical stimulation applied in the treatment of acute and chronic skeletal injuries promotes wound healing. To evaluate the effects of electrical stimulation on the mechanical properties of healing skin, this study used the denervated limb trochanteric pressure sore model developed in pigs (1). Twenty Hanford mini-pigs with trochanteric pressure ulcers were subjected to electrical stimulation applied to the periphery of wounds for two hours per day. Examination of the biomechanical properties of the skin, and changes in wound area and volume were done on previously wounded and healing pigskin subject to AC or DC electrical stimulation. The behavior of normal pigskin was compared to: (a) denervated controls, (b) denervated AC stimulated, and (c) denervated DC stimulated skin. Each treatment group was analyzed relating the orientation of the healing skin with regard to the stimulation electrode. DC and AC stimulation appear to enhance the healing of pressure ulcers by reducing wound area and increasing the vascularity of healing tissue.

## Materials and Methods

A denervated limb trochanteric pressure sore model developed in house permitted the use of a 2.5 cm percutaneous cancellous bone screw for wound formation and a 3 cm diameter spring compression indenter to maintain a constant pressure of 800 mmHg for 3 days. Reproducible and uniformly controlled Grade 3 or higher tissue ulcers were created in the monoplegic hind limbs of 20 Hanford mini-pigs weighing 10-15 kg. Denervation was accomplished by right unilateral extradural rhizotomies from L2 to S1 nerve roots. Half of the pressure wounds created over the right trochanter were electrically stimulated; the other unstimulated half of the wound served as the denervated control. Specimens from the opposite limb were used as normal controls.

Electrodes (Encore Plus) were placed 1 cm distal and proximal to the wound periphery. DC amplitude was less than 1 mA; maximum current density in the wound area between electrodes was 30-80 $uA/cm^2$. AC supplied from a programmable current stimulator (Frederick Haer Co.) was applied as a form of charge balanced tetanizing current (4 sec ON, 4 sec OFF) for 40 Hz repetition frequency and 300 msec pulse width. The measured current density was 1189±219 $uA/cm^2$. Wounds were stimulated 2 hours/day, five days a week for 30 days. After sacrifice all limbs were kept frozen at -20°C.

## Mechanical Testing

A dumbbell shaped template, used to outline the tissue area of constant dimensions was centered through the would and surrounding tissue. After marking the template, the entire skin sample was shaved, cut and stored in saline. Sections were oriented both parallel (through the healing area) and perpendicular (adjacent to the healing area) to the current flow. Evaluation of specimens included quantitation of tissue thickness at the various regions using a Mitutoyo thickness gauge to within an accuracy of 0.01 mm.

Dumbbell shaped specimens were uniaxially loaded in tension until failure at an extension rate of 150 mm/min on a Chatillon test system. 10 mm wide specimens had a length to width ratio of

6:1. Mechanical properties were calculated from load deformation curves. The maximum stiffness was derived from the linear slope of the curve between 20-80% of the stress at failure. ANOVA was used to analyze the data.

**Area and Volume Time Constants**

At weekly intervals, changes in wound area and volume were obtained from photographs and direct measurements to estimate the healing rate. Biopsies were obtained from the wound margin for histomorphometric analysis of the vascularity of the healing tissues. The number and size of the blood vessels were measured and statistically evaluated using ANOVA.

**Results**

Tables I and II show the mechanical property data for all tested skin specimens subject to electrical stimulation. With the exception of strain values obtained for DC stimulated and denervated controls, there were no significant differences in the mechanical properties of samples oriented perpendicular to the current flow. The applied current caused no change or reduction in strength of the skin tissue perpendicular to the current flow. In Table II, the stiffness values for healing wound and skin samples oriented parallel to the current flow were reduced by nearly half the values obtained for normal controls. Furthermore, while the strength of the healing tissue was less than that of normal skin, the applied current did not reduce the strength of healing wounds below the unstimulated values. Statistical differences ($p < 0.05$) were found only for stress, Young modulus and stiffness when compared to normal skin. Samples oriented in the perpendicular direction were comparable to normal skin (p=NS).

The change in wound area and wound volume was observed to follow an exponential function. The area and volume time constants were calculated by fitting the measured wound area and volume to an equation of exponential form. Both AC and DC stimulation shortened the area time constant, but they had little effect on the volume time constant. (Table III). Histomorphometric analysis revealed that AC and DC stimulation increased the number of vessels in the healing tissue. DC stimulation also increased the vascular area.

**TABLE I**

**MECHANICAL PROPERTIES OF PIGSKIN ORIENTED PERPENDICULAR TO THE CURRENT FLOW**

| | Stress (MPa) | Strain (%) | Modulus (MPa) | Stiffness (N/mm) |
|---|---|---|---|---|
| AC (N=16) | 10.69±2.96 | 60.15±31.02 | 21.77±11.03 | 24.5±11.9 |
| DC (N=9) | 13.06±3.77 | 76.44±18.49* | 17.63±4.90 | 22.5±7.7 |
| DEN CONTROL (N=13) | 10.66±3.60 | 54.03±15.30* | 22.05±11.08 | 25.0±10.9 |
| NORMAL (N=45) | 12.25±4.95 | 73.43±32.72 | 20.06±10.22 | 20.8±8.1 |

* p<.05 versus control

TABLE II

MECHANICAL PROPERTIES OF PIGSKIN ORIENTED PARALLEL TO THE CURRENT FLOW

| | Stress (MPa) | Strain (%) | Modulus (MPa) | Stiffness (N/mm) |
|---|---|---|---|---|
| AC (N=18) | 6.67±3.92* | 55.07±28.57 | 12.88±7.63* | 17.1±11.0* |
| DC (N=12) | 4.73±2.60* | 61.92±30.58 | 7.58±3.28* | 14.6±8.4* |
| DEN CONTROL (N=15) | 4.90±2.42* | 45.65±26.57 | 11.27±8.36* | 15.2±8.1* |
| NORMAL (N=43) | 10.87±3.90* | 58.17±20.91 | 20.45±8.67* | 27.7±11.0* |

* p<.05 versus control

TABLE III

VASCULARITY, WOUND AREA AND WOUND VOLUME TIME CONSTANTS

| Blood Vessel | AC | DC | Denervated Control |
|---|---|---|---|
| Number (/mm$^2$) | 21.6±8.0* | 19.2±8.2* | 9.4±3.1 |
| Area (×10$^{-3}$ mm$^2$/mm$^2$) | 31.6±13.4 | 52.8±17.2* | 31.6±13.9 |

| Time Constant | AC | DC | Denervated Control |
|---|---|---|---|
| Area (days) | 9.4±2.5 | 9.7±3.1 | 13.5±7.5 |
| Volume (days) | 4.0±0.6 | 5.3±2.5 | 5.1±2.3 |

* p<.05 versus control

**Conclusion**

The mechanical properties of healing pigskin are modified and show a directional variation when electrically stimulated. Both AC and DC stimulated wounds showed: (1) a reduced healing time when compared to controls and (2) enhance the healing of pressure ulcers by reducing wound area and increasing the vascularity within healing tissue. Electrical stimulation may stimulate wound healing by orienting collagen formation in a pattern similar to normal skin even in the absence of neural influences.

**Acknowledgements**

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Helen E. Kambic, M.S.
Biomedical Engineering & Applied Therapeutics (Wb3)
The Cleveland Clinic
9500 Euclid Avenue
Cleveland, OH 44195

# IMPROVED GAIT AND MOTOR CONTROL POST HEAD INJURY FOLLOWING FNS EXERCISE AND GAIT TRAINING

Janis Jacobs, Katherine Barnicle, E.B. Marsolais
Motion Studies Laboratory
V.A. Medical Center, Cleveland, Ohio

ABSTRACT

Conventional neurorehabilitation techniques are often not adequate to restore walking and motor control following traumatic head injury. In this case study, the subject was treated using an FNS system with intramuscular electrodes and a multi-channel stimulator. Treatment included 2 1/2 years of FNS-driven gait training and exercise. The subject improved from chair dependent to walking 50 feet with one cane. Muscle function improved several muscle test grades. The degree and timing of improvements are beyond clinical expectation of spontaneous recovery. Results indicate the importance of a future controlled study.

## INTRODUCTION

Following traumatic head injury, conventional neurorehabilitation techniques are often inadequate to restore walking and motor control. This case study investigated the results of using an intramuscular electrode FNS system to improve gait and motor control.

## METHODS/MATERIALS

### SUBJECT

The subject was a 23 year old male with a traumatic head injury. A bullet was excised from his motor cortex along with surrounding damaged tissue. He was in a coma for 21 days, after which he was triplegic. He participated in inpatient rehabilitation for 6 months; at the time of discharge, he was paretic in both lower limbs and had a mild coordination deficit in the right upper limb.

He entered the research program 6 months post injury. He was completely unable to move the right leg for swing initiation. He moved the left leg in a flexion reflex pattern only. He was able to bear weight on both limbs as long as extensor spasticity was operative. Bilateral voluntary quadriceps strength and control was poor.

### TREATMENT METHODS

Subject SX performed FNS exercise and gait training three times weekly over a period of 2 1/2 years (excluding 2 months per year for vacation). The exercise and gait training was provided using intramuscular electrodes and leads exiting through the skin to connect to a portable stimulator.

Figure 1 illustrates the two FNS treatment phases A and B. In Phase A, FNS-driven gait practice was provided for 10 months. In phase B, three interventions were added: FNS walking speed control; FNS-driven or assisted exercise for isolated joint movement control; standing alignment/balance control exercise .

### Muscle Implantation Procedures And Equipment

Muscle testing, video documentation, and visual movement analysis were performed to detect motor control dysfunction.[1] Electrodes were implanted in those muscles exhibiting dysfunction in isolated movement control and/or in gait pattern movement. Muscles implanted were: left gluteus maximus, quadriceps femoris, posterior tibialis, anterior

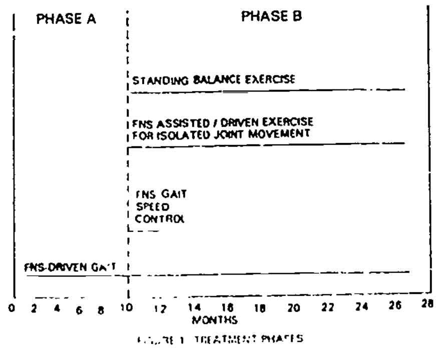

FIGURE 1 TREATMENT PHASES

tibialis, gastrocnemius/soleus, peroneus longus/brevis; right sartorius, gracilis, gluteus maximus, gluteus medius, posterior adductor, biceps femoris short head, quadriceps femoris, tensor fasciae latae, peroneus longus/brevis, anterior tibialis.

Electrode implantation was performed using a local anaesthetic. The electrode was made from fine 10-strand stainless steel Teflon-coated wire, with polypropylene core for durability and a double helical configuration for flexibility.[2]

Control of Stimulation

A specialized computer program, Vortex[3] was developed to be used on a Digital Equipment corporation MicroVAX II to create FNS patterns. This program provided capability to devise a stimulation pattern using all the implanted muscles in multiple combinations and timing variations. The portable stimulator was based on a V40 (NEC) microprocessor. Preprogrammed patterns were used in daily sessions for exercise, gait training, walking endurance, stair-climbing, side and backstepping.

Data Collection

Video documentation of functional capability was made using a Panasonic Industrial Camera and a SONY U-Matic Cassette Recorder (VO-5600). Muscle function was tested using standard manual muscle test positioning, along with goniometric measurement of active movement.

RESULTS

WALKING CAPABILITY

Overall, Subject SX improved from chair dependency to walking 50 feet repeatedly with 1 cane (Figure 2).

Fatigue and ankle instability prevented him from ambulating longer distances without the FNS. With FNS, he was able to walk one mile.

VOLUNTARY JOINT MOVEMENT IN THE RIGHT LOWER EXTREMITY

<u>Muscle Test Results.</u> Figure 3 shows change in muscle function of selected right lower extremity major muscle groups over a 28 month period. Conventional muscle testing procedures were used (except in the case of the right knee extensors which lacked 5 degrees of extension during sitting, but could hold against maximum resistance). Hip and knee flexors and extensors showed improvement beginning at month 6, with greatest additional improvement between month 22 and 28.

DISCUSSION

<u>Correlation of Treatment With Improvements.</u> The first dramatic improvement occurred during Phase A in which FNS-driven gait was provided. Phase B was initiated (FNS-driven exercise for isolated joint movement control) at month 10 because very little change in muscle function (Fig. 3) was observed between month 6 and 10. Three months after initiation of Phase B, improvements were documented in hip and knee flexors (Fig 3).

By month 18 in the study, Subject SX was 2 years post injury. From a clinical perspective, at two years post injury , one would expect that most spontaneous recovery would have already occurred. However, from month 22 to 30 in the study, the muscles demonstrated additional recovery. Improved muscle function is reflected in the improved ability to walk, using canes at month 26.

<u>Significance of the Study.</u> There was no control for spontaneous recovery in this case study. However, in spontaneous recovery from head injury, one would not expect the degree nor the timing of the recovery documented in this case. These results indicate that a controlled study may be of value to determine the effects of using IM electrode FNS driven exercise and gait, designed to improve voluntary motor control post head injury.

Acknowledgements

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Janis Jacobs, M.S.
Motion Study Laboratory
V.A. Medical Center
10701 East Blvd.
Cleveland, Ohio 44118

Figure 3. CHANGE IN MUSCLE FUNCTION OVER 28 MONTHS

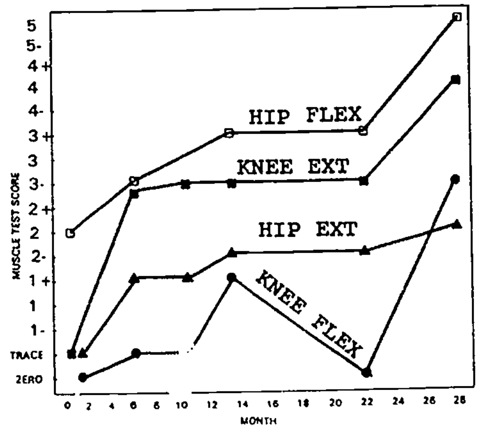
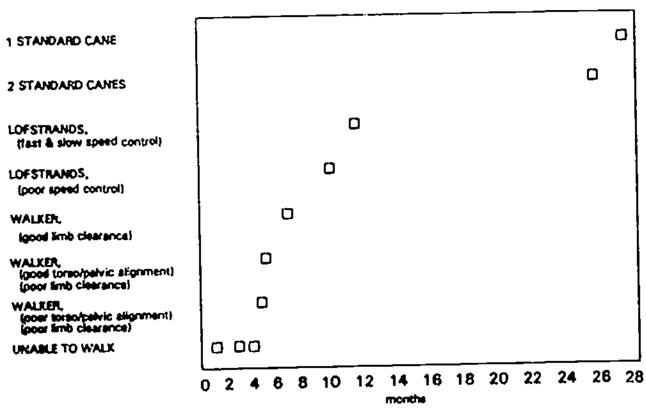



FIGURE 2. CHANGES IN VOLUNTARY GAIT CAPABILITY



3.1

# SELECTING TEXT FOR MANIPULATION IN A GUI THROUGH SCANNING

F. Shein, M.Eng., P.Eng.,
The Hugh MacMillan Rehabilitation Centre, and
Department of Industrial Engineering, University of Toronto, Toronto, ONT

## ABSTRACT

This paper further elucidates some of the concerns of access to a graphical user interface (GUI) through scanning presented earlier by the author and describes an ongoing investigation. Details are provided that illustrate the specific problems that arise when providing equivalent functions to the mouse to select text for manipulation using various scanning solutions. These solutions are implemented using the most recent version of WiViK©, a visual keyboard for Windows 3.0® and OS/2 2.0®. Five different strategies are compared.

## BACKGROUND

Earlier papers by the author and his research team have pointed out the significance and problems associated with direct manipulation in a graphical user interface (GUI) [1, 2]. Solutions have been proposed and studied relating to pointing devices and in the use of visual keyboards displayed on a computer screen [5]. A software product, WiViK, a visual keyboard for Windows 3.0 has been developed that resolves most concerns associated with on-screen keyboards used with pointing devices [4]. However, issues related to scanning are still unresolved and are under current investigation.

Selection of chunks of text for editing is a task in which a pointing device excels, while posing a daunting problem for the scanning user. Here, the user must position the pointer to indicate insertion points and to mark blocks of text for editing (e.g., cutting, copying, pasting, and formatting). In addition to incorporating cursor movements as selection set items within the visual keyboard, a typical solution is to include block actions (e.g., selecting the next or previous character, word, sentence, or paragraph).

Informal observations of this approach suggest that it is not ideal because it requires the user to make repetitive selections of cursor movement keys while shifting attention between the text and the visual keyboard. Between selections, the user must decide what command to choose next. The result is slow, awkward interaction prone to errors in proportion to the many selections made.

A new alternate access system for the Macintosh, Ke:Nx,™ provides the user with a roving pointer cursor that moves (scans) in the direction selected by the user. By directing the pointer cursor, the user has full access to manipulating text/data and all GUI gadgets. Normal scanning within a visual keyboard is also provided for text entry, thus the user can emulate both the keyboard and pointing device with scanning. This appears to be a good solution, but is the user really achieving direct manipulation? Repetitive movement and attention switching between the roving pointer cursor and items in a visual keyboard can be a frustrating experience. Stopping the cursor at a precise location, e.g., between two characters, requires very good physical control. 'Bumping' the cursor one or a few pixels is possible, but time consuming.

Clearly, more research is required to develop solutions that are functional and benefit the user. Some preliminary work had been undertaken into the manipulation of text through scanning blocks of text in succession from paragraphs, through sentences, words and characters [3]. A more stringent examination and analysis of the issues related to selecting text through scanning is still required so that we can design more effective solutions, not just novel solutions.

## GOAL

The goal of the current investigation is to compare the effectiveness and relative merits of several cursor movement scanning strategies for selecting chunks of text for manipulation and to suggest reasons for selecting a particular strategy. Four different strategies for moving the insertion point cursor within a text editor by selecting movement commands within a visual keyboard are being studied. A fifth strategy involving a roving screen pointer cursor is also being examined.

These strategies are applied to a common visual keyboard layout with a single scanning technique. Examples presented here assume that the user is employing row-column scanning using two switches; one switch to make selections, the second switch to escape out of an undesired scanning sequence. The issue under consideration is not how to effectively scan and use switches, but how to effectively employ strategies to get the most out of the scanning.

It is recognized that individual motor, cognitive, and visual-perceptual abilities and their limitations due to disability, may in the end dictate the effectiveness of a strategy independent of its merits or disadvantages. Therefore, a sub-objective is to gain an understanding of the mechanisms by which users react, adapt, and strategically employ each of the strategies.

Testing of the strategies with users is underway and final data is not yet available. Therefore, this paper is limited to identification of the user demands and a discussion of the advantages/disadvantages of each strategy based upon preliminary observations.

## STRATEGY DESCRIPTIONS

*1. Standard cursor movement*
The standard method is to repeatedly select movement keys from within the visual keyboard to move the insertion cursor over the text one step at a time. Visual keyboard keys may be defined to move the cursor in blocks (word, paragraph, home, end, page up and page down) if the text editor supports such functionality. Fortunately, most applications today, such as those within Windows 3.0 provide these capabilities in a generally consistent fashion across applications. Keys may also be designed to send a macro set or series of keys.

***2. Repeating keystrokes***
An enhancement to the standard method is to allow selected keys within the visual keyboard to repeat continuously until stopped by the user. For example, activating a switch to select a key may initiate repeating; activating the switch again may then stop the action and allow scanning of the visual keyboard. This is analogous to holding down a key on the keyboard to repeat it.

***3. Imbedded multiple repeating keystrokes***
A further enhancement is to imbed multiple repeating keystroke actions within a single visual keyboard macro key. One key may be defined to move the cursor first by paragraphs, then by lines, words, and characters. Another key may be defined to move first by lines, then by words, and characters; and another by words followed by characters. Repeating single character movement keys would remain. Each repeating action would be stopped and the next one initiated by a switch activation. With this strategy, it is necessary provide a second switch as an 'escape' so that the user

can exit from the sequence of repeating levels at any time to prevent overshooting the target.

*4. Emulating the visual keyboard scanning method with the text*
By using the strategy of imbedding multiple repeating keystrokes, it is possible to emulate the same visual keyboard scanning technique to select text. Rather than moving the insertion point cursor within the text area, blocks of text are highlighted in succession. The user focuses on the target and waits until it is highlighted by a block. When highlighted, the user activates their switch and waits again until it is highlighted by the next smaller size block. This is repeated until the desired location is reached.

With row-column scanning, the lines of text could be viewed as rows; words as columns of smaller rows; and characters as columns within a word. In comparison to the previous strategy, the starting point for the scanning would be consistent, e.g., from the left-most word of a line, and the left-most character of a word.

*5. Roving cursor*
An entirely different approach is to apply the scanning technique to the pointer cursor (i.e., the cursor that typically moves with the mouse) as with the Ke:Nx. Hence, the heading (or direction of movement) of the cursor can rotate continuously or in fixed steps at some scan interval to set a heading to move, and it can move along that heading in a similar scanning fashion. The intent is to emulate the actions of the mouse. Both heading rotation and distance movement keys must be included within the visual keyboard. With this strategy the pointer cursor is 'blind' to the text beneath it, while the insertion cursor movement techniques allow movement relative to the units of text. The roving cursor strategy has the power, however, of being able to move anywhere within the GUI. A technique of displaying the heading through a line from the tip of the cursor is introduced here as a way of improving feedback to the user.

## USER ACTIONS

The actions that the user must follow for each strategy are now described for moving the insertion point to a target location. Selecting a block of text then requires selecting an extend function followed by a repetition of the actions to select the end point of the text block. Each of the first four strategies can be applied using a similar looking visual keyboard as shown in the figure below; the look is the same in all cases, but the actions vary:

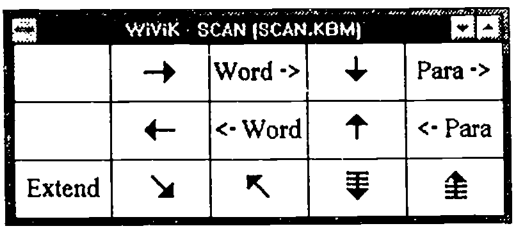



*Figure 1: Possible visual keyboard display of cursor movement keys for the first 4 strategies.*

The first four strategies share the initial steps described below:

- locate target
- locate insertion cursor
- compare target location with insertion cursor and decide upon the largest cursor movement key (block unit) that will bring the insertion point closest to the target
- select the appropriate cursor movement key

The remaining steps are described below:

*1. Standard cursor movements*
- repeat the basic steps listed above until the target is reached

*2. Repeating keystrokes*
- continuously observe the insertion cursor move and compare its position with the target to ensure that it does not overshoot the target
- stop the repeating cursor movement action at the point where the next movement would overshoot the target
- repeat prior steps with smaller units of cursor movements until the target is reached

*3. Imbedded multiple repeating keystrokes*
- continuously observe the insertion point move and compare its position with the target
- stop the repeating cursor movement action at the point where the next movement would overshoot the target; or escape out of the sequence of repeating cursor movement levels if the next movement level would overshoot the target (if escaping, it is necessary to repeat the steps from the beginning until the target is reached)
- repeat the previous two steps with the successive movement levels defined for the selected key until the target is reached

*4. Emulating the visual keyboard scanning method with the text*
- continuously observe the blocks of text being highlighted
- stop the repeating highlighting action at the point when the target is contained within the highlighted block or escape out of the repeating sequence to select the highlighted block
- repeat the previous two steps with the successive block movements levels defined for the selected key until the target is reached

*5. Roving cursor*
- locate target
- locate pointer cursor
- identify cursor heading by selecting a visual keyboard key to display the heading (optional)
- compare cursor heading with heading towards the target and decide upon the largest available rotation that will bring the pointer heading in-line with the target
- select the appropriate heading rotation key within the visual keyboard
- continuously observe the heading line rotate and compare with the target to ensure that it does not rotate past the target
- stop the repeating rotation action at the point where the next rotation would overshoot the target or escape out of the sequence of repeating rotational levels if the next rotational level would overshoot the target (if escaping, it is necessary to repeat the steps from the beginning until the heading intersects the target)
- repeat the previous two steps with the successive rotational levels (smaller angle) defined for the selected key until the target is intersected
- compare target location with pointer cursor and decide upon the largest available cursor movement (distance unit) key that will bring the pointer cursor closest to the target
- repeat the above steps using the cursor movement keys as in the previous strategy until the target is reached

## DISCUSSION

*1. Standard cursor movements*
This strategy is the most obvious implementation and can be readily implemented with any visual keyboard. The drawback is that it is very slow and demanding. To speed up cursor movement and reduce selections within the visual keyboard the user must carefully choose efficient block cursor moves. Each single cursor movement demands a selection from within the visual keyboard and requires the user to constantly alternate attention between the

keyboard and the text. With every shift in attention the user must re-orient themselves with respect to the focus of activity. There is a constant potential of losing sight of the target and the insertion point, thus increasing search time. The number of switch activations (and possibility of error) associated with scanning (at least 2 activations per selection) rises directly in proportion to the number of steps that the user must make.

*2. Repeating keystrokes*
Immediate performance improvements can be expected with this strategy because it eliminates the need to select a key more than once if it is to be repeated. Thus one key may be repeated *n* times with only 2 switch activations within the visual keyboard and 1 activation to stop the repeating, that otherwise would require $2*n$ activations. The number of attention shifts between the keyboard and the text would also be reduced to once per selection. While the cursor is stepping through the text, all attention is placed on the text. However, the user must still be vigilant in comparing the location of the insertion cursor and the target with every step the insertion cursor makes. Since it is 'easy' for the stepping insertion cursor to do most of the work, efficient jumps to the target may be ignored, such as with the home, end, page up, and page down keys.

*3. Imbedded multiple repeating keystrokes*
This strategy further eliminates the need to shift attention between the visual keyboard and the text. Any target position within a body of text might then be reached through the selection of a single key, provided the user makes no errors. The total number of switch activations levels off at a maximum of 2 activations within the visual keyboard plus up to 4 activations while stepping through the text. Thus, this strategy is somewhat independent of the distance travelled. The advantages of this strategy are diminished by the demands associated with the vigilance required in comparing the insertion cursor and target location and in deciding when to activate the switch to move to the next repeating movement action to ensure that the cursor does not overshoot the target. Also, the use of a second switch as an escape mechanism becomes essential so that the user can exit at any level of block movement. However, even if overshooting occurs, error correction can be achieved rapidly by repeating the process although at a cost of further similar switch activations.

*4. Emulating the visual keyboard scanning method with the text*
The number of required switch activations with this strategy is the same as the previous one but there are two subtle differences. The first relates to the feedback associated with the highlighting block versus the moving cursor. Waiting until the target is contained within a highlighted block facilitates the decision as to when to make switch activations. The second difference is that movement always starts from the top or left-most position of the previous block because there is no insertion point for relative movement as with the previous strategies. Thus, the number of movement steps may be greater.

*5. Roving Cursor*
This strategy is similar to the imbedded repeating scan strategy except that it may require twice as many switch activations—a minimum of two selections (rotation and distance) or a base of 4 activations plus up to $2*4$ activations (if 4 rotation/movement levels are defined) to rotate and move the cursor. Linking movements directly following rotations is possible but not feasible since particular distance movements do not logically follow the setting of a heading. Hence, it would be necessary to have a variety of starting distances associated with each starting rotation.

For users familiar with a mouse, this approach may seem intuitive—simply point to where you want the cursor to move and then step towards it along a straight line. Generally, a user may go from one point to any other point on the screen with one heading setting. However, accuracy of the pointing decreases with distance from the starting point of the cursor since the arctangent of the angle swept by the rotation increases with distance.

Movement across a window may be enhanced by examining the window and determining its dimensions and moving relative to it. (This is feasible due to the technical design of GUIs.) For example, distance movements may be in relative amounts of the window such as quarters, and quarters of quarters and so on. This strategy may also be enhanced by sweeping out a pie segment in front of the heading, analogous to highlighting a row of text. In a manner similar to the fourth strategy above, the user would activate a switch to stop scanning when the target is included within the highlighted area.

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## ADDRESS

Fraser Shein
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, ONT,
Canada M4G 1R8

# Full Visual Annotation of Auditorially Presented Information for Users Who Are Deaf: ShowSounds

Gregg C. Vanderheiden, Ph.D.
Trace R&D Center
University of Wisconsin-Madison
Madison, WI

Abstract
Speech and sound are being used more and more in computer and information systems which had previously been strictly visual. As the use of sound is incorporated more and more into these systems, individuals who are deaf are going to face increasing difficulties in accessing and using these systems. Since these will appear in education and employment as well as daily living, access to these systems is essential.

A standard cross-platform strategy for providing access to the sounds is proposed, in the form of a ShowSounds "switch" which could be built into the systems. Flipping this (software) switch would cause the information being presented auditorially to also be presented visually. This would apply both to information presented by the operating system and to individual application programs that supported this capability. This visual annotation would go beyond just captioning, and would include other visual display as necessary to convey any important information presented auditorially.

## Background

Currently, people with hearing impairments have little or no difficulty in using computers. The use of sound as a standard feature has been minimal, usually no more than a "beep." Often, the beep is accompanied by some other indication of the error, so that missing the beep is not critical to operation.

However, the increasing sophistication and quality of synthetic and digital speech technology has made it easier and more desirable for computer companies and applications software companies to consider incorporating more extensive use of sound into their products, including voice output. Where this sound and music is merely decoration, and is not necessary for the operation of the computer or program, no serious access problem is posed. Where important information content is contained in the audio portion of the software, the access issue becomes pressing for people who are deaf or who have severe hearing impairments. As computers and consumer products are slowly merging with each other, and with emergency of multi-media education, game and information systems, the use of sound and speech is going to escalate. The result is likely to be an ever-growing body of material and products which will be partially or substantially inaccessible to persons who are deaf or who have severe hearing impairments.

## Proposed Solution Strategy

To address this problem, it is proposed that a "ShowSounds" capability be introduced within multi-media, computing, and information technologies. This ShowSounds capability would in some ways resemble closed captioning of television programs, but would also support more extensive sound annotation capabilities.

Like closed captioning, the ShowSounds capability would allow users to indicate whether they wanted to have sound annotation visible. For individuals who could hear, the ShowSounds feature would be entirely invisible. However, if an individual had a severe hearing impairment, or was in an environment where noise interfered with hearing, they could turn on the ShowSounds "switch" or setting. Once the ShowSounds was turned on, the audiovisual material would automatically provide visual annotation for all important auditory information.

## More Diverse Visual Annotation

Since the computer-based information and multi-media systems have considerably more intelligence and graphic capabilities than television, the types of annotation that could be provided could also be more diverse. For example, with ShowSounds turned on, a program presenting information via speech would automatically begin showing captions as well. Another program which used a rising and falling tone to indicate information would simultaneously display a small scale with a rising and falling pointer to correspond to the tones. Beeps or other tones meant to draw one's attention back to the screen would be accompanied by a screen flash or other visual event substantial enough to catch one's attention if one were looking at the keyboard or elsewhere. In this fashion, video annotations could be tailored to best present the auditory information in a visual format.

## System Support for ShowSounds Visual Annotation

In order to facilitate the implementation of visual annotation and to encourage the use of standard approaches, tools or utilities can be built directly into the operating systems of computers or information appliances. All of the modern operating systems have extensive toolboxes which application programs use for creating windows, dialog boxes, menus, etc. These toolboxes could be extended to also include tools for captioning, flashing sections of the screen, or other visual annotation techniques. Developers of applications/products which incorporate voice or information-carrying sounds could then easily add the visual annotation capabilities to their applications/products by making use of these built-in tools.

The basic system would also have to support some user-accessible ShowSounds "switch." In computers, this would typically show up in the control panel for the operating system, the same place where one adjusts the volume of the computer, the sensitivity of the mouse, the keyboard repeat, etc. By having this ShowSounds switch located at the operating system level, an individual would be able to turn the switch on once when they sat down at the computer, and all programs, applications, and system functions using sounds would check the switch and present visual annotation of sound events.

As computers incorporate text-to-speech capabilities directly into their operating systems, an auto-captioning capability could be included. In this fashion, text sent to the computer's operating system to be spoken could be automatically displayed as a caption as well. This would relieve the application software of this task, and make the captioning feature work even with non-ShowSounds-aware programs. This auto-captioning feature should have a software over-ride that would allow the application software to prevent an item from being captioned. This would be useful in a number of instances: spelling tests (where children who can hear might turn it on, so that they could see how to spell the words being presented); situations where the text being read aloud is already present on the screen; and situations where the application program would like to provide shorter or differently worded captions. The application program would also be able to specify where on the screen the caption would appear, so that the caption could be positioned so as not to obscure important information on the screen.

As companies such as Apple, IBM and Microsoft begin developing multi-media control utilities, it will be important to build in the necessary tools to facilitate access by individuals who have hearing and other impairments.

**Plan for Implementation**

Implementation of this recommendation could be carried out in stages. In fact, it would need to be, since the later stages require built-in text-to-speech capabilities which are not a standard part of computer operating systems today.

The stages for implementation by operating system and base platform manufacturers would be:

*Stage I: Implementation of ShowSounds Switch by Operating System Manufacturers*

1) Inclusion of a ShowSounds switch in the control settings for the operating system by operating system manufacturers;
2) Implementation of visual events to correspond to any sounds created by the operating system;

*Stage II: Support for ShowSounds by Applications Programs*

3) Provision of visual indication of any important sound events created by application program if ShowSounds is switched on;

*Stage III: Provision of Sound Annotation Tools in Operating System*

4) Provision of ShowSounds closed-captioning tools for use by third-party developers; and
5) Provision of auto-captioning capabilities in connection with any system-based voice utilities.

Application programs could begin to check for the ShowSounds switch and provide visual cues for any auditory events as soon as Stage 1 is completed.

Application programs most likely to first make use of such a switch would be programs designed for education or designed specifically for the disability field. However, government legislation regarding computer access may encourage the use of the ShowSounds switch by business software vendors as they incorporate sounds into products which they would like to sell to the federal government.

**Progress to Date**

Some progress has already been made toward the goal of producing support for the ShowSounds capability across company and product lines.

- Discussions are underway with Apple Computer Corporation regarding the inclusion of a ShowSounds switch as a part of their standard control panel for sounds in future versions of their operating system.
- A ShowSounds feature has been incorporated into the AccessDOS software package, which is distributed IBM as a complement to its DOS operating system. AccessDOS provides several important disability access features for IBM PC and PS/2 computers running DOS. (In AccessDOS, the ShowSounds switch is currently tied to a feature which causes either a small note in the upper left-hand corner of the screen or full-screen flash whenever a sound of significant length is initiated by the computer.)
- The ShowSounds feature with accompanying screen flash is also included in the next release of Access Utility to be distributed by Microsoft for Windows™.
- The ShowSounds concept is included in the White Paper prepared by the Trace Center and the Information Technology Foundation (ITF) (formerly the ADAPSO Foundation). The White Paper is the first step toward the development of a set of design guidelines for the application software industry. ITF is a non-profit foundation of the Information Technology Association of America, the trade association for most of the major application software companies in America. The guidelines are being developed in response to a request by industry for direct industry-usable information as to how software products can be designed to be more accessible to people with disabilities.

These efforts to develop the ShowSounds concept are also being coordinated with the Caption Center, a service of the WGBH Education Foundation. The Caption Center, through its Media Access Research and Development Office, is leading a multi-faceted effort to provide access to all types of media–television, radio, print, live performance, theatrical, film, and other.

**Conclusion**

Initial efforts have begun toward the implementation and support for such a ShowSounds feature on a number of computer platforms. Much work is needed, however, to make both computer and information system vendors aware of the need for such a capability, and to build it into their next generation systems.

**Acknowledgements**
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For more information, contact: Gregg C. Vanderheiden, Ph.D., Trace R&D Center, S-151 Waisman Center, 1500 Highland Avenue, Madison, WI 53705-2280

3.3

# EVALUATION OF THE DATAHAND™ KEY ENTRY SYSTEM FOR PHYSICALLY CHALLENGED USERS


Leland W. Knight, Associate Professor, Arizona State University
James B. Koeneman, Ph.D., Head of Bioengineering, Harrington Arthritis Research Center
William R. Ferrell, Ph.D., Professor, University of Arizona



ABSTRACT

The DATAHAND™ key entry device takes a fundamentally different approach to user wrist and hand position, and finger function, for data entry to the computer. This new product is configured to allow the operator comfortable hand and finger motion with individual adjustment inherent when in use. Positive responses to comfort and function by users in empirical evaluations suggest this key entry design may have unique and positive benefits for users with hand pathology.

This paper presents the rationale and proposed method for the evaluation of the health benefits associated with this new concept.


INTRODUCTION

Various new key entry products are in the development stage, or will shortly be marketed. In general, these designs offer better function and health for the user. However, none of these designs reflect the degree of change incorporated in the DATAHAND concept; Figures 1 and 2. The keyboard is replaced by two hand units which support the hands and allow for individual positioning of hands in the x position with respect to the users shoulder width. With DATAHAND the operator can rest their forearms on the chair armrest, with hands supported by each palm unit. This design also allows individual positioning in the y position of the operators hands during use. A new five way keying switch module makes all keys "home keys," and places the fingers several millimeters from each key cap. This reduces strike force and provides differential feedback to the operator. Thumb keys control function modes and commands to the computer. In sum, this concept (a) supports the hands (b) keeps the wrist joint straight and (c) reduces finger force to actuate keys.

This configuration removes the load from the arms and hands required with the standard keyboard now in use. It is expected that this reduction in support needs and force requirements will be of substantial benefit to both normal and physically challenged users.

ANALYSIS

A biomechanical analysis was conducted on the DATAHAND. The DATAHAND results were compared to those when the hand is using a standard keyboard input. The position of the hand , magnitude of joint reaction forces, the number of repetitions, support of the hand, and which muscles are used were considered.

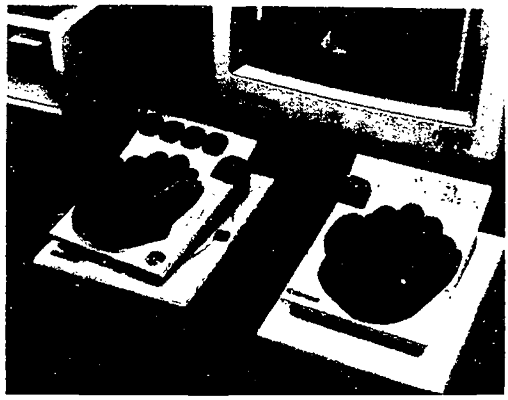

Figure 1

Figure 2

HAND POSITION

The hand is in the "Position of Function" when using the DATAHAND (Fig.3) [1]. Three main advantages of this position are (1) muscle tension does not have to be applied to bring the fingers into the working position, (2) the moment arm of the force applied to the finger tip is reduced, (3) the angle of the wrist is such that high pressures are not produced at the carpal tunnel. The position of the finger for normal keyboard input is shown in Fig. 4. The fingers are extended past their resting position.

JOINT REACTION FORCES

The compression forces which are generated across the joints of the fingers during function are especially important if the person has arthritis. High joint forces can accelerate the disease process.



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High joint forces may also lead to earlier initiation of osteoarthritis. Fig. 4 shows the position of a finger when typing on a standard keyboard. Two flexor tendons are shown. The profundus tendon attaches to the distal phalanx and the sublimis tendon attaches to the middle phalanx. For the purpose of calculating the joint reaction force at the metacarpal phalangeal (MP or knuckle) joint these two tendons are taken as one. Fig. 5 shows the vector sum of these forces in two dimensions. The joint reaction force is eight times the applied load at the tip of the finger. Fig. 6 shows the configuration of a finger when using the DATAHAND. The applied load is shown as 0.6 of the load applied to the normal keyboard. Because of the geometry, the joint reaction force is lowered to about one-third of the standard keyboard joint reaction force as shown in Fig. 7. The magnitudes of the joint reactions and the lowering of the joint reaction force with fingers in a flexed position are consistent with the calculations of others in the literature [2].

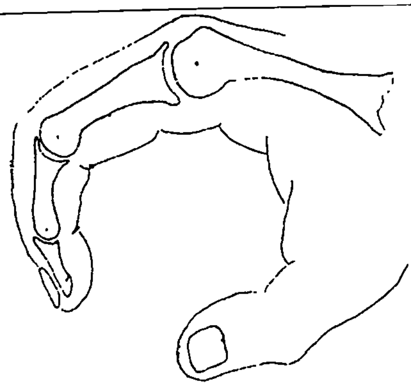


Figure 3 "Position of Function" of the Hand

82 mm x P = T x 10 mm
T = 8.2 P

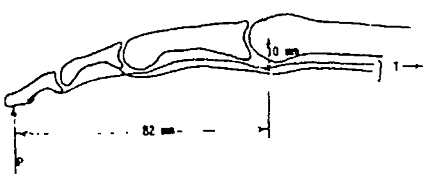
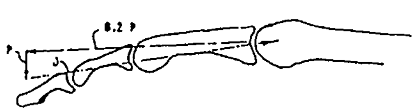



Figure 4 Standard Keyboard Finger Position




J = 8.0 P Joint Reaction Forces
Figure 5 Standard Keyboard Joint Force at MP Joint

## HAND SUPPORT

The hand is supported in the "Position of Function" by a molded support in the DATAHAND. The fact that the finger extensor muscles are not needed to maintain this position has already been discussed. Supporting the hand also relieves the duty of the trapezius muscles which are needed to hold the hands above the keyboard of a standard data input terminal. Another advantage of hand support is that it acts as a finger brace. The flexor and extensor tendons of the hand run in sheaths which are attached to the bones by ligamentous pulleys. Since the phalanges (finger bones) are at an angle to the metacarpal bones, the tendons make an angle at the MP (knuckle) joint. If the ligamentous supports of the tendon sheaths are stretched because of trauma or a disease process such as rheumatoid arthritis, the tendon will bow string. Normal and stretched extensor tendon paths are shown in Fig. 8. With each extension or flexion of the stretched hand, the bow string causes a bending moment to further stretch the soft tissues. Repetitions of flexion and extension cause the typical appearance of the windswept or ulnar deviated hand. This is because the already weakened constraint ligaments are forced to carry substantial forces during hand function. These forces stretch the ligaments further which leads to the vicious cycle which leads to extreme deformities in these types of hands. Keeping proper alignment of the fingers and metacarpals will reduce this phenomenon. The hand support will act as a brace which is the treatment for many rheumatoid hands.

## MUSCLE ACTIVATION

There are two groups of muscles which control the hand, the intrinsics and the extrinsics. The extrinsics are located in the forearm and are the stronger of the two sets of muscles. The extrinsics are used for power such as grasp and pinch activities. The tendons of these muscles pass through the carpal tunnel of the wrist. Repetitive motion of these tendons can initiate and/or aggravate carpal tunnel syndrome (CTS). CTS is pain, numbness, and tingling of the hand caused by pressure in a bony tunnel in the wrist through which the flexor and extensor tendons pass. The intrinsic muscles are located within the hand and provide the control and balance for fine hand function [3]. Since these muscles are within the hand their tendons do not go through the carpal tunnel. Since the motion of the fingers is a very fine movement, much of the finger motion when using DATAHAND will be activated by the intrinsic muscles. The excursion of the tendons will be much less with the DATAHAND because the sum of the angular motions of all the finger joints

$$0.6 \times 60\ \text{mm} = T \times 10\ \text{mm}$$
$$T = 3.6\ P$$

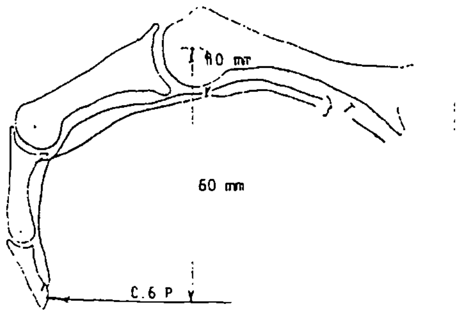



Figure 6 DataHand Finger Position

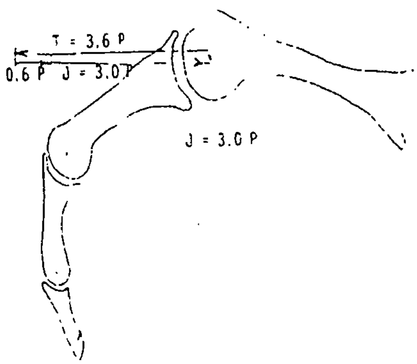



Figure 7 DataHand Joint Reaction Force at MP Joint

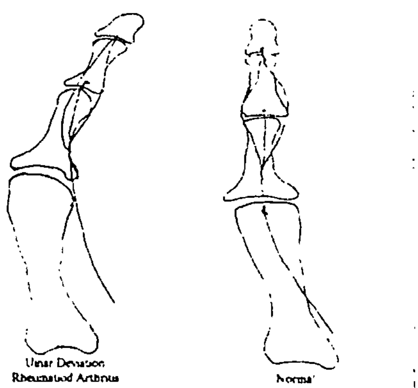



Figure 8 Dorsal View (Viewing Back of Hand)

is much less with the DATAHAND than during normal keyboard operation. The operation of the DATAHAND will employ several different muscle actions thus reducing the number of repetitions of any one motion. This may be an advantage for reducing muscle fatigue.

SUMMARY

This preliminary study indicates the DATAHAND has several biomechanical advantages over conventional keyboards. For people with hand pathology such as those with arthritis, the joint forces will be reduced and the number of repetitions at the same location reduced. Deformations of the constraining ligaments will also be reduced. People with arthritis also often have reduced muscle strength. The lower muscle activity required by the DATAHAND would be a great advantage to this population. Potentially there should be less pain for osteoarthritics. Studies will be done to verify the results of this preliminary study. Experimental measurements of emg signals by the various muscle groups will be made. The contact forces will be measured and the muscle fatigue assessed after long term use.

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Leland W. Knight, Associate Professor
School of Design, Arizona State University
Tempe, AZ 85281 2105

# The Synergy Computer -- Beyond the Laptop

Dawn Russell, M.A., CCC-SLP and Emily Hoeffel, Ed.D.
Synergy – Adaptive Innovations

Abstract

This paper discusses a computer system developed to address the unique needs of persons with physical and/or speaking disabilities. This IBM-compatible, weather resistant computer system, *Synergy*, provides modular components that allow for optimal attachment to a wheelchair. The body of the computer, including processor and hard drive, can be placed in the back of the wheelchair and powered by the wheelchair battery. A flat panel display can be mounted at the optimal site for visual access. The choice of adaptive input also can be mounted separately, at the optimal site for physical access. If speech output is desired, one of many high quality speech cards can be installed within the *Synergy* system without adding any external components. Since the *Synergy* system is powered by the electric wheelchair's battery, it is able to run for an entire day without requiring batteries to be replaced or recharged. Furthermore, the processor, memory and hard drive within the *Synergy* system are easily updated with "off-the-shelf" components available from any computer store. Any MS-DOS software can be used with the *Synergy* system.

## Background and Statement of Problem

For maximum integration, persons with disabilities need a means to write, retrieve information and speak in all environments. For many this means using a portable computer mounted to their wheelchair and accessed using adaptive inputs. Typically, laptop computers have been used to meet these needs, however, laptops have presented several limitations. For instance, laptops require a new battery every one to three hours. Often the person with disabilities is unable to change these batteries by themselves and requires assistance.

Furthermore, laptop computers are a single unit. This makes them convenient for non-disabled persons to carry, however, for individuals who use adaptive access to the computer, a single unit is more difficult to attach to a wheelchair, since the entire computer, including CPU and keyboard must be attached to the front of their wheelchair so that the display can be visible. Even individuals who use adaptive inputs and are unable to use a standard keyboard must have the entire laptop, with keyboard, mounted to the front of their wheelchair.

Another limitation individuals have experienced with laptop computers is in updating components as technology advances. For instance, if a laptop's processor becomes outdated, they must replace the entire computer. In contrast, users of desktop computers are able to update their processors by simply replacing the processor card.

Individuals who are non-speaking and use dedicated communication devices rather than laptop computers have experienced even greater difficulties in gaining access to writing and information retrieval. If they require access to a computer, they often are provided with a separate desktop computer, set up with their adaptive access equipment or accessed via their dedicated communication system. Therefore, these persons can speak anywhere, but they can take notes, write letters, etc. only at the site of their adapted computer.

## Design

Our goal in developing the Synergy computer system was to provide a standardized computer system which would meet the unique needs of persons with physical disabilities who use require adaptive access to a computer. We aimed to provide a single consistent system that would be available in all environments. Furthermore, we wanted the system to be cost effective and affordable.

The Synergy computer system provides modular components that allow for optimal mounting to a wheelchair. The computer, with processor, hard drive and floppy drive, can be placed in the back of the wheelchair and is powered by the wheelchair battery. The flat panel display can be mounted separately at the optimal site for visual access. The input device can also can be mounted separately, at the optimal site for physical access. If an individual cannot use a standard keyboard, then one is not attached to their computer. If speech output is desired, one of many high quality speech cards such as DECtalk, which is a full-size card, can be installed within the computer system without adding any external components. Also, for speech output, a speaker is embedded within the flat panel display.

The system is designed to be weather resistant. You do not need to remove or protect your system when traveling in inclement weather. It is also designed with industrial quality components to accommodate the jarring which frequently goes hand in hand with the use of a power wheelchair.

The system is powered either by the electric wheelchair's battery or by an external long-life battery. Unlike a laptop computer whose batteries need to be changed every one to three hours, this system runs all day on a single nightly charge. There is also the option to power the computer by plugging it into a wall outlet.

The Synergy system accepts any IBM-compatible component and therefore provides all the capabilities of a desktop computer. For instance, if you wish to control the Synergy computer via voice input, you can install Dragon Dictate's full size card.

Since each component is separate, the Synergy computer allows you to modify your system as technology improves or as your needs change. For instance, you can change the way you access the Synergy computer from an expanded keyboard to a single switch by simply detaching the keyboard, plugging in a switch and installing the appropriate adaptive software. Likewise, if you find that you need a more powerful processor, you can upgrade the processor without having to replace the entire computer.

The system has been designed to be cost effective from many perspectives. Since the Synergy computer does not require the proprietary components of a laptop computer, it can be inexpensively repaired or upgraded by anyone familiar with IBM-compatible computers. The processor, memory and hard drive within the system are easily updated with "off-the-shelf" components available from any computer store. You can add a megabyte of memory to the Synergy computer for no more than $70 rather than the $300 that it would cost to do the same to a typical laptop. If the system ever needs repair, you can bring it to any local computer repair facility familiar with IBM-compatible computers.

Development

Our initial design and development process included initial attempts to disassemble and "repackage" a laptop computer. However, we found significant limitations which ultimately demonstrated that this was not a viable route to pursue. We felt that it would be more effective to develop a computer system designed from the outset to meet the specific needs of individuals with disabilities. The system as it presents today is the result of many design modifications based on feedback from field test applications. For example, as a result of the attempts by clients to achieve maximum independence, hardware on, off and reset switches have been incorporated into the design.

Evaluation and Discussion

The *Synergy* computer system is serving an essential function in enhancing the independence of individuals who use power wheelchairs. The system provides the capabilities of a powerful IBM-compatible desktop computer in a form that is portable and can be optimally mounted to a wheelchair and powered by the wheelchair's battery throughout the day.

The thrust of our development efforts has been to provide individuals with the tools to function at the highest level of independence and to enhance their integration into the mainstream educational program or workplace.

For instance, using the Synergy computer, students can participate in a group writing activity as they and their peers are gathered around a table. Professionals can take notes during a meeting or access information while visiting a client. Those who require augmentative communication can "talk" and use their computer simultaneously.

Dawn Russell, M.A., CCC-SLP
Emily Hoeffel, Ed D.
Synergy-Adaptive Innovations
66 Hale Road
East Walpole, MA 02032

# A Two-Class Information Model for Access to Computers and Information Systems by People Who Are Blind

Gregg C. Vanderheiden, Tom Andersen,
John Mendenhall and Kelly Ford
Trace R&D Center
University of Wisconsin-Madison
Madison, WI

**Abstract**
Graphical user interfaces are now becoming the major mode of interacting with computers and the next generation of information systems. In trying to assess the problems created by these types of interfaces for people with disabilities, substantial confusion has been created by the lack of distinction between true graphic information and the use of graphical metaphors to represent concepts such as files and commands. Based upon the work developing alternate access systems for Macintosh™ and Windows™ computers, a two-class information model is advanced. Its purpose is to clarify and facilitate research and education on accessibility issues surrounding graphical user interfaces. The model is also intended to be applicable and extensible to virtual reality and other interface systems which use metaphors to facilitate presentation or control of information.

**Background**
Interaction with computers involves both presentation and manipulation of information, as well as the issuing of commands. The information may be of different types, including verbal, spatial, or graphic information. Commands can by typed, selected from a list, etc.

Originally, computer displays were text-based. Information could only be presented as running text, spatially organized text, or with a graphic created by arranging single characters (letters, numbers, or graphical characters) to create a rough "picture." The commands were similarly issued either through typing the commands into the computer (as text) or through selecting commands from menus displayed on the screen in text.

Because of the heavy text orientation of these systems, individuals who were blind were able to develop and use text-reading strategies to access and use the computers. Products known as screen readers were used to read the information displayed as text on the screen, using voice synthesizers, or to send the information to a braille display. The information that was presented spatially (that is, by its position on the screen) could also be accessed through the use of screen navigation commands and the ability of the person who was blind to maintain a picture of the screen layout in their mind.

Although they were able to access much of the information on the screen, the screen readers were not able to access drawings or diagrams, even if the drawings were created using letters of the alphabet. Except for very simple stereotypic graphic "drawings," it was extremely difficult or impossible for a person who was blind to form an accurate mental picture of a drawing on the screen created with characters. Thus, even on character-based computers, graphic presentations of information were not necessarily accessible. In addition, many character-based programs also had graphic modes, which they would switch into when presenting charts, diagrams, or other graphic elements. Since these modes of operation were pixel-based, the screen readers would essentially be blind whenever the graphic modes were invoked.

*Graphical User Interfaces*
With the advance of graphical user interfaces, the entire screen was converted into a pixel-based system. This allowed for the easy intermixing of text and graphics. Furthermore, the graphics were used not just to display graphic information, but also to allow elaborations on how text was presented (different fonts, styles, attributes, etc.), to help indicate organization and grouping of various text elements on the screen (documents, dialogs, menus), and to display available commands such as page up, page down, document size, etc.

**The Problem**
Because everything from text to system commands are now being displayed graphically, the perception was that all of this would be as inaccessible as graphics were when they did appear on character-based computers. The most obvious problem with graphical user interfaces was that screen reading software had difficulty accessing the text on these screens. Strategies have since been developed, however, to overcome this first barrier.

Another major barrier appeared to be the existence of icons, windows, and other graphic elements on the screen, which were presented graphically rather than as characters. For the traditional screen reading approaches, which were designed to read characters only, these graphic elements appeared to present a large new barrier. As a result, individuals who were blind were not only unable to access true graphic information (which was also *not* accessible with character-based systems), they were now also unable to access the basic display and command structures necessary to access text (which they *did* have access to with character-based systems). However, most of the graphic elements (icons, windows, etc.) are only graphic representations of concepts which could *also* be presented verbally (spoken or in braille).

In other words, many of the "new barriers" that were perceived as being created by graphical user interfaces are in fact artifacts of the way in which the information is being presented to sighted users. There is, in fact, nothing inherently graphic about the underlying concepts, and they can, if desired, be presented in verbal (speech, braille, etc.) form as well. Other information which is inherently graphic (charts, drawings, etc.) would, however, still present the same access problems as it did in the character-based systems. However, the inability to easily distinguish between these two types of "graphic" information has caused much confusion in the field.

**The Model**
The proposed model seeks to separate the inherent nature of the information being presented from its pre-

sentation format. For example, if there is a command such as "Delete," which could be presented either with the word "Delete" or with a picture of scissors, that command would be classified the same. The fact that a particular operating system chose to represent it as the word or as a picture does not make the underlying concept (Delete) more or less graphic.

Although different classifications schemes could be used, the interest here is in mechanisms for providing access for persons who are blind. An objective of this model, therefore, is to help separate those elements to which we can provide access in a rather straightforward fashion, using speech or braille, from those for which other techniques would be needed in order to provide access. The model therefore uses a verbal/nonverbal scheme, and classifies the different types of underlying information into those which can be expressed in words (Class 1) and those which cannot (Class 2). For the graphical user interface command with Macintosh™ and Windows 3.0™ environments, this two-class model is shown in Table 1.

**Table 1:**
**Delineation of Elements in the Macintosh™ and Windows 3.0™ Environments According to the Model**

*Class 1*: Information that can be presented in words (e.g., spoken or in braille)

- *Systems contructs* (e.g., windows, menus, dialogs)
- *Text*
- *Text attributes* (e.g., bold, italic, font, font size)
- *Icons* (small images that always appear exactly the same)
- *Auto-interpretable images* (stereotypic graphics or nonverbal sound that can be computer-interpreted and completely described by words)

*Class 2:* Information that is inherently graphic and cannot be described easily and completely with words.

- ***Line drawings, simple charts, maps***
- ***Gray-scale pictures, etc.***
- ***Three-dimensional images***
- ***Animated images***

As can be seen, the classification of information is somewhat dependent upon our current level of technical sophistication. Simple charts which can be easily interpreted by a computer and changed into a verbal description would fall into Class 1, while more sophisticated charts would remain in Class 2.

**Access to Class 2 Information**
Since the information in Class 2 by definition cannot be accessed purely through verbal means, other strategies can and are being explored to allow access. Among these are the virtual tactile tablet, different uses of sound, and kinesthetics (the sense of where one's body and limbs are in space). One system which combines a number of these strategies is the Systems 3 prototype being developed at the Trace Center working in conjunction with Berkeley Systems, Inc. of California. This prototype combines verbal (speech or braille) output with two-dimensional sound and a virtual tactile tablet to allow access to graphics such as bar charts, pie charts, line drawings, etc. With the system, the individual can feel the image while using sounds to provide spatial and textual information. The system also provides better access to spatially arranged text such as sparsely populated charts, flowcharts, etc.

It is not yet possible to access all types of Class 2 information with this system. For example, the system does not provide any access to gray-scale pictures or very complex graphics, nor does it address three-dimensional or animated presentations. However, as computer image interpretation algorithms are improved and applied to this area, the amount of information that can be accessed by people who are blind can be continually increased. Moreover, this not only applies to information which originates on the computer, but also to pictures, diagrams, and images which appear in print and daily life. With the use of scanners and digitizing cameras, it is now possible to easily capture these pictures and move them into the computer, where these types of special graphics access interfaces can allow the user who is blind to explore the images.

**Applications of the Model**
This model is not limited to the types of user interfaces that are common today. It also applies to pen-based computing and virtual realities, as well as to future information technologies yet to be developed. In each of these environments, this model can be used to separate true graphic, true gesture, or true three-dimensional information from graphic, gestural, or three-dimensional *metaphors* for concepts which could *also* be completely represented verbally.

The model also gives two directions for further work to improve accessibility. The first is to find ways to convert Class 2 information into Class 1. An example is software that can interpret stereotypical graphics such as bar and pie charts and present them verbally. The second direction is to develop technology for improving access to Class 2 information. Examples in this area include large, fast interactive tactile displays; image enhancement; image separation; video annotation systems; and computer-assisted interpretation of graphics.

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Gregg C. Vanderheiden, Ph.D.
Trace R&D Center
S-151 Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280

# SEE, HEAR & TOUCH THE GUI: COMPUTER FEEDBACK THROUGH MULTIPLE MODALITIES

Deborah I. Fels[*], G. Fraser Shein[f], Mark H. Chignell[*], Morris Milner[f]
[*]Department of Industrial Engineering, University of Toronto
[f]Hugh MacMillan Rehabilitation Centre

## ABSTRACT

Computers have opened a new world for people with disabilities allowing them to communicate, work, and interact. Through innovation and modification, computers can be made accessible to many people regardless of any limitations. Much emphasis has focused on input techniques for the human-computer interface and on improving the visual presentation of information. However, as these visual presentations become more sophisticated, exemplified by Graphical User Interfaces (GUIs), access for people with visual or cognitive impairments often becomes more difficult. A model of feedback that is independent of sensory modalities (i.e., visual, auditory and tactile) is presented that separates information, such as a system message, from its presentation attributes such as screen coordinates, colour or pitch. This information can be conveyed through one or more different sensory modalities without losing the context and content of that information. The benefit of providing information through multiple modalities is that designers are not restricted to the visual modality and that people with visual impairments can gain equal and functional access to the user interface.

## BACKGROUND

Computers are able to offer many exciting and unique opportunities to people with disabilities for communication, daily living and work. For example, people with visual impairments can use screen reading systems that "speak" the text appearing on the screen. It is important to examine, improve and generalise the underlying concepts of the user interface so that software can be designed that accommodates the various needs of all people. By studying the logic of feedback to users from computers and developing a language which describes it in a generic form, the theoretical foundations of the user interface can be expanded and improved. Expressing feedback though a common language layer will enable application programs to be developed that can be used by people with disabilities as well as the able-bodied population.

Feedback from the computer about what it is doing is a critical component of the overall usability of a computer system. It must be tailored for each user as well as for each task. Currently, users must adapt to pre-defined computer interfaces which present information almost exclusively in a visual form. If users cannot adapt to this feedback arrangement, they must find alternatives or systems customised to meet their needs.

Humans are able to combine five modalities (hearing, vision, touch, smell, and taste) to receive and process stimuli and feedback from the environment. In contrast, computers for general use can be characterized as "mono-sensory" in that most of the information is conveyed through one main output device, the visual display terminal (VDT) which uses only the visual channel (Buxton, 1987). This excludes users who are visually impaired or who find visual feedback too complex or too confusing to comprehend.

Hence feedback should be provided through multiple channels using the visual, auditory and tactile sensory modalities (Shein, Brownlow, Treviranus, & Parnes, 1990). **Figure 1** illustrates this concept of expressing computer feedback through different sensory modalities. By incorporating multi-modal feedback design features into standard software such as a word processor, the software can be made more universally accessible.

The concept of modality independence is similar to the notion of device independence. Device independence means that information from input devices or graphical images can be categorised into generic and standard classifications (Baecker & Buxton, 1987). An example of a device independent classification system is the Graphical Kernal System (GKS). It defines the types of information from input devices and screen graphics to/from application programs as logical or virtual devices defined by function rather than form (Van Den Bos, 1983). All information provided by input devices such as location or text can be classified into these categories. GKS assumes that feedback is conveyed through the visual modality and does not consider other output channels (such the auditory or tactile channels).

Systems 3 developed by Vanderheiden, G.C., and Kunz, D.C. (1990) is a system which uses tactile and voice output to represent the graphical user interface to a blind user. Graphical information, such as an icon, is converted to an auditory description as well as to a tactile representation of that visual image in the tactile screen space (virtual representation of the screen). This system attempts to preserve the spatial information that is inherently provided by the visual display on thecomputer monitor. However, it does not standardise the language of the user interface but translates what is presented visually directly into an auditory and tactile description.

A system that has recently been introduced is IBM's ScreenReader/PM for OS/2 which produces an aural translation of a GUI. This system uses a database (off-screen model) to track and manage all of the items that are represented on the screen (Schwerdtfeger, 1991). It assigns all of the information on the screen along with identifying attributes such as font, colour, and point size to a place in the database. This system directly translates what is on the screen to a spoken equivalent via a speech synthesizer. In some instances, some pre-processing does occur so that information such as changes in colour are represented by words which convey the meaning of the display (e.g., the active window is usually visually indicated by a change in colour, and auditorily represented by telling the user the title of the active window instead of the colour). This system, however, does not decipher the underlying semantics of the information but directly conveys what is presented on the screen. In addition, the off-screen model has limited capacity to convey icons and graphical images so that they have equivalent auditory significance.

## STATEMENT OF PRC LEM

Much of the current research in rehabilitation engineering has focused on designing better input techniques and systems. Less effort has been placed on how to tell the user what is going on within the machine (feedback).

The goal of this research is to develop and test the viability of a feedback system whereby information is presented to the user from a computer in generic terms independent of the modality. Instead of device independence with respect to input devices, this research

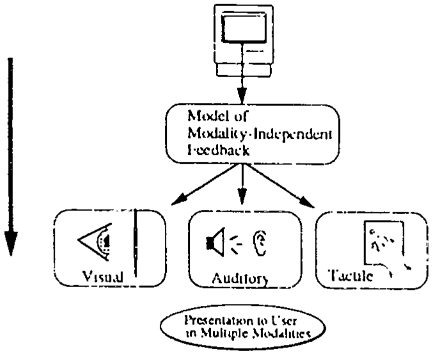


Figure 1: A Model of Modality-Independent Feedback

will focus on classifying and expressing information from application programs that is independent of modality. This information could then be translated by physical devices such as VDTs, speech output devices and braillers into a modality appropriate for each user.

*Research Hypothesis*

The hypothesis of this research is that much of the information conveyed to users by the computer can be expressed completely through one or a combination of the three modalities (auditory, visual or tactile).

## APPROACH

A taxonomy of feedback techniques is being developed based on information gathered on input as well as an in-depth investigation of existing word processor systems. Word processing systems are the most commonly used software for computerised augmentative communication systems. The taxonomy discussed in this paper is a first attempt at defining a standardised nomenclature as well as a structure of the various relationships between the different types of feedback. Smalltalk/V ™ for Windows 3.0, an object-oriented programming environment, is being used as the development tool for the taxonomy and the model of the project.

Based on preliminary work by Fels (1987), eight general categories have been defined to describe information that is presented to the user by the computer:

1) ***message***;
2) ***block***;
3) ***prompt***;
4) ***set of choices***;
5) ***cursor***;
6) ***alphanumeric***;
7) ***symbol***; and
8) ***graphics***.

The ***message*** object provides system status information to the user (e.g., error message). A ***block*** object separates related information from other information that is available to the user (e.g., a window). A ***prompt*** asks the conceptual question "what should be done next" and requires an answer from the user (e.g., a button in a dialog box). The ***set of choices*** object is a grouping of choices from which the user must select one item (e.g., a menu). A ***cursor*** indicates the operational location of, and may also indicate function within, the application currently in use by the user (e.g., arrow cursor for a mouse). These five categories provide the context through which information is expressed.

***Alphanumeric, symbol*** and ***graphics*** objects represent how information is communicated and expressed to the user through a linguistic or graphical form. These three categories provide the content of the information.

Computer feedback objects for augmentative communication aids such as scanning arrays, menus, and visual keyboards as well as for Windows 3.0 have been defined using this hierarchical classification system. An example of a visual keyboard object that has been classified using this system is illustrated in **Figure 2**. It is defined as a set of letters displayed on the screen that a user can select (and enter into another application program) by pointing to a letter with a pointing device. It is an alternative to the keyboard for people who cannot type using a standard keyboard (Shein, Hamann, Brownlow, Treviranus, Parnes, & Milner, 1991). As seen in **Figure 2**, the visual keyboard is classified as a block that is comprised of a prompt, a cursor and graphics. The content of the prompt, in turn, is a set of choices which consists of alphanumerics and graphics. The cursor is comprised of a graphic.

The approach taken in classifying these objects has been to organise them from the "top down". The top-most level(s) in the hierarchy provides the context of the keyboard object and the lower levels define the content. From the example, the top-most level of the visual keyboard is the block. The next level providing additional context for the keyboard object is a prompt and a cursor. The prompt and cursor are contained within the block and are specific to the objects within the block regardless of other items that exist outside of the block region. The prompt is described by two lower levels that provide the context and content of the prompt: a set of choices which is the set of keys available to be selected; and each key (choice) has a graphic represented by its surrounding box and an alphanumeric represented by a letter as its content.

## DISCUSSION

Currently, these categories only define static information presented to users. Functionality or dynamic information remains to be defined within the taxonomy. For example, an arrow cursor is different than a bar cursor. While both specify location information (i.e., operations are performed at the cursor location) there are inherent differences in functionality. The arrow is associated with pointing to a location followed by a selection while the bar is associated with entering data at that location.

In addition, a strategy for presenting information in each modality in an appropriate and acceptable format must be developed. For example, the best method to present emphasis on an object, such as indicating the active application window, may be to vary the pitch in the auditory domain and change the colour in the visual modality.

## IMPLICATIONS

The implications for this system are that much of the feedback displayed by computers and computerised communication aids can be defined independent of the modality used to express this feedback. This means that the GUI can be accessible to people who currently have difficulty understanding the feedback presented to them or who cannot see what is presented to them on a computer screen. Handling the graphical component of the user interface in a useful and meaningful way for people with visual impairments is not implemented in any of the available screen reading software. By describing graphical information using the

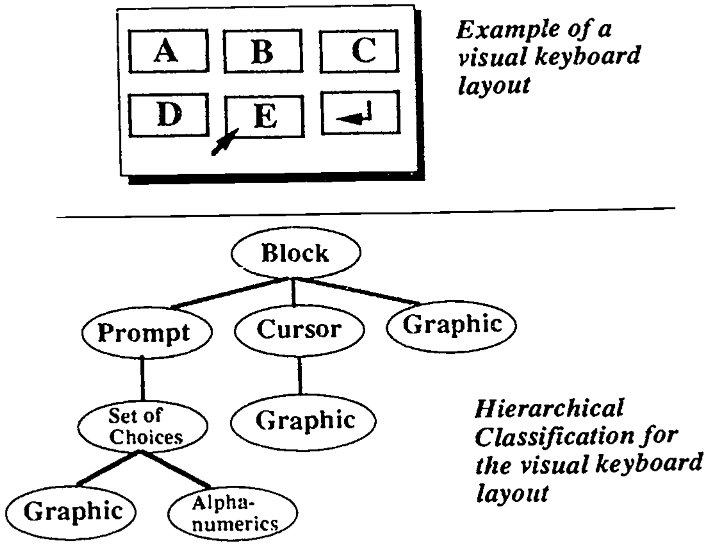


Figure 2: Classification of an Example Visual Keyboard Layout

auditory or tactile modality, people with visual impairments will have a better understanding and ability to work with the GUI without losing the information that is conveyed by the graphical objects.

In addition, at a more fundamental level, a theory of how computer feedback can be categorised and expressed as generic information that is independent of modality will contribute to a more complete model of the user interface. This will assist designers in the development of application programs that use the auditory, visual and tactile modalities.

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## ADDRESS

Deborah Fels
Hugh MacMillan Rehabilitation Centre
350 Rumsey Rd.
Toronto, Ont., Canada M4G 1R8
email: fels@phoenix.rose.utoronto.ca

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# Voice Recognition as an Alternative Computer Mouse for the Disabled

Gerald Miller, PhD
Bioengineering Program, Texas A&M University

## ABSTRACT

Analysis of voice recognition as an alternative computer mouse controller for handicapped users was conducted. A prototype system was developed consisting of a series of bandpass filters with logic controls. This system was connected to a computer bus mouse controller card inserted in a 386 PC. Standard mouse movement commands were incorporated into the design including "left", "right", "up", "down", "stop" and "click". Speaker independence, recognition accuracy and reliability, and cost were design features incorporated into the prototype development

## INTRODUCTION

Many individuals suffer from severe handicaps such as quadriplegia, paraplegia, or limited motor function resulting from a variety of neuromuscular disorders. Limitations in motor function and coordination prevent the use of standard manually operated devices in the workplace and home environment. Typical of such devices is a microcomputer, whose primary inputs include such manually operated devices as a keyboard, mouse, joystick, touch screen, and light pen. These devices are relatively inexpensive and are designed for an able bodied population. There are fewer options available for a disabled population of potential computer users (Miller, et al, 1989).

Voice technology has recently been employed to allow interface to a computer for both handicapped and able bodied individuals (the latter group for cases where hands-free computer input is required). Utilizing standard word processing languages, a voice processing system can be tailored to provide text input and to control common computer functions including control of the operating system. These voice processing systems usually employ a computer board with accompanying software. Difficulties associated with the use of voice recognition as an input to actuate devices include speaker dependency, background noise, excessive speaker training, recognition accuracy and repeatability, and expense. These issues have been addressed by Miller and Etter (1990), Bristow (1986) and Schroeder (1985) among others. Customized voice recognition systems have also been developed for non-computer applications including usage by a disabled population. One such system was developed to control the motion of a motorized wheelchair for quadraplegics (Miller, et al, 1985)

The control of cursor movement by voice, similar to that achieved manually with the use of a computer mouse, has been restricted. A manually operated mouse is a simple and inexpensive input device involving potentiometers which control cursor movement through a serial port or bus mounted board. The development of a voice activated mouse should be similarly simple to operate and inexpensive.

This paper outlines the development of a voice activated computer mouse for use in controlling screen cursor movement, in a manner similar to that achieved by a manually operated mouse. The device consists of a series of bandpass filters with logic controls which interface to a bus mouse computer board through a standard 9 pin connector.

## DESIGN AND DEVELOPMENT

The voice activated mouse is designed to provide six words to control screen cursor movement: up, down, left, right, stop and click. The system is utilized to drive a bus mounted mouse on an IBM compatible 80386 microcomputer. System constraints include speaker independence and simple user training. A Logitech bus mouse card is used for interfacing purposes.

The system schematic diagram is shown in figures 1. The microphone is wired to the input of a 741 op amp connected as an inverting amplifier to magnify the signal fifty times. The output of this amplifier goes through a buffer before going to both the 1000 and 1600 hertz filters. The buffer eliminates impedance mismatch problems between the preamp and filter stages. Both filters are active second order bandpass filters with Q values of ten and gains of two. As the Q value increases, undesirable frequency components are attenuated more. The output signals of both filters then go through respective variable amplifiers and then to respective rms to dc converters. The signals from the variable amps are full wave rectified and then low pass filtered to provide outputs proportional to the magnitude of the ac signals. Both dc outputs are fed into a comparator. Through experimentation it was determined that if the variable amp for the 1000 hertz signal is set at an amplification of 12.6 times, and the amp for 1600 hertz signal is set at 2.6 times, the comparator output can be used to differentiate between certain vowel sounds for both workers on this project.

A trigger is used to activate the first timer. The trigger consists of a comparator which has a high output whenever a person speaks. A high voltage corresponds to approximately five volts while a low voltage corresponds to about zero volts. The two inputs to the trigger comparator are a dc voltage proportional to the 1000 hertz filter output and a constant .5 volts. Hence, if the dc signal from the filter is greater than .5 volts, the comparator output goes high. The design of the trigger mentioned above which incorporates the 1000 hertz filter eliminates the problem of background noise activating the remaining circuitry. Large capacitors are connected to the output of the comparator. The voltage after the capacitors pulses high when a word is spoken. This pulse activates the switch which triggers the first timer by shorting the timer input to ground. The timers are in a cascade arrangement as can be seen from the schematic. These one-shot timers have a high output for the period of time specified in the schematic. At the end of 50 milliseconds, the 100 millisecond timer is triggered and so on. The first timer clears the flip-flops and the shift register in the parallel loading mode.

In order to recognize short words, a shift register is used, which when clocked, loads data serially. At 155 ms, the serial shift register is clocked so that data is loaded and shifted. If the spoken word has been completed, and therefore the trigger comparator output is low, then through digital logic circuitry, a high is loaded to the shift register. The shift register has five outputs, such as "LLLLL." The L is for low and an H is high. If a short word is spoken, the outputs would change to "HLLLL." If a long word was next, the outputs would be "LHLLL." Using digital logic circuitry, if the first output is high, the second output of the shift register is low, the "stop" flip-flop is activated. If both the first and the second outputs are high, the "click" flip-flop is activated. If the first output of the shift register is low as in the first and third examples above, neither of these two flip-flops is activated. The spoken word must last less than 155 milliseconds to be recognized as a short word. A shift register connected so that data is loaded in a parallel fashion and a decoder is used to determine the longer words. The five inputs to the shift register are transferred to the five corresponding outputs only when the shift register is clocked. The three bit decoder has three inputs and eight possible outputs (000,001,etc.) The output of the decoder corresponding to the three bit input only goes high when the decoder is enabled with a high voltage. At 155 milliseconds the parallel shift register is clocked. Only two inputs and outputs are used. If the word is still being spoken at 155 milliseconds, one of the two will be high and shifted to the shift register output. The comparator output which the filter inputs is used to determine which output will go high. Two of the decoder inputs are these two shift register outputs. The third decoder input is the trigger comparator output which is high if a word is being spoken and low other wise, as mentioned earlier. These three decoder inputs yield five combinations. All of the decoder inputs may be low indicating no word longer than 155 milliseconds has been spoken. The input from the trigger comparator maybe high or low, and either but not both of the two inputs from the shift register may be high. This arrangement just described yields four more possibilities. The decoder in enabled at about 500 milliseconds after the word begins. When the decoder is momentarily enabled, the appropriate decoder output goes high briefly as well. These decoder output signals are used to trigger the appropriate flip-flops. Thus, short spoken words (with short vowel sounds) must last between 155 milliseconds and 500 milliseconds, and longer words (with long vowel sounds) must last longer then 500 milliseconds for the desired output to be activated.

The flip-flop are cleared at the beginning of each word so that the flip-flop outputs and inverted outputs are low and high respectively. These output levels will not turn on the light emitting diodes (LEDs) or activate the corresponding relays. However, when a flip-flop is clocked, the output goes high and the inverted output goes low which lights the desired LED and closes the switch in the relay. The relays are wired to jacks so that six switched outputs are obtained. The two short words and the four longer words yield six combinations which activate six different relays. These outputs control cursor movement as a computer mouse does. Interconnections are made to a standard 9 pin connector for a bus mouse card.

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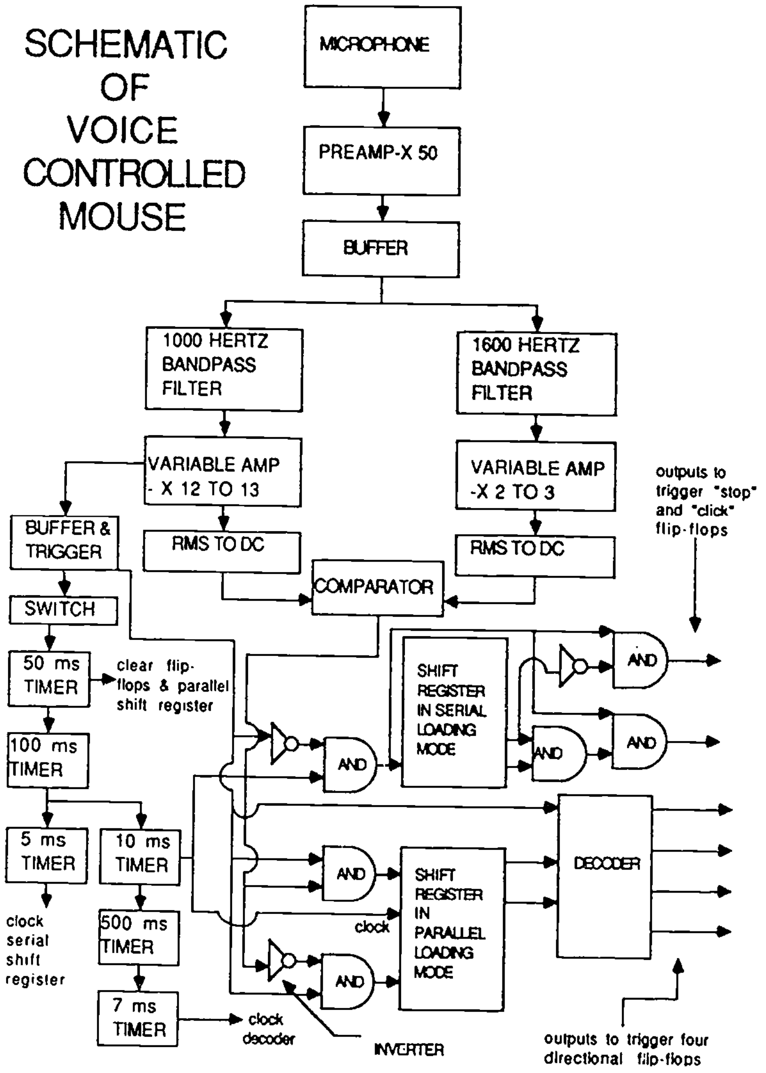


Figure 1. Schematic of Voice Activated Computer Mouse

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# UTILIZING SPEECH RECOGNITION TECHNOLOGY TO INCREASE PRODUCTIVITY -- CASE STUDIES

**Hong Z. Tan & David M. Horowitz**
Center for Rehabilitation Technology
Dept. of Rehabilitation Medicine
Tufts University School of Medicine, Boston, MA

## ABSTRACT

A comprehensive vocational service delivery model using speech recognition technology was presented earlier [1] and has been applied with success. Here, we present two case studies. One of the two clients, JEM, is an architectural designer, who is quadraplegic, and who wishes to regain self-employment. The other client, HK, is a vocational rehabilitation counselor, who suffers from multiple sclerosis, and who requires assistive technology to increase her productivity on the job. While HK's main concern is to document her cases in a timely fashion (she is barely able to type), JEM needs to document building specs as well as to draft blueprints. JEM's rehabilitation program involves more technology compared to HK's. The results are encouraging. We are convinced that when knowledge engineering[1] is applied to voice recognition technology, productivity is increased. A person with a disability utilizing such assistive technology is in a strong competitive position with his/her able-bodied counterparts. Issues concerning psychosocial/medical aspects of our rehabilitation program are also addressed.

## BACKGROUND

There are approximately 650,000 individuals in the United States who experience complete paralysis of all extremities due to a variety of neuromuscular disorders (source from Washington D.C., Data on Disability from the National Health Interview Survey 1983-1985). The extent to which disability impairs manual dexterity contributes to the problems individuals with quadriplegia face in achieving gainful employment. In view of these statistics, there are many individuals who could benefit from speech recognition technology.

Speech recognition allows individuals to speak to a computer to dictate correspondence or operate software, instead of typing. Despite the enormous potential speech recognition offers individuals with severe disabilities, there are very few detailed case studies in the rehabilitation literature on the vocational applications of speech recognition. (For a more thorough literature review, see [1]).

Although there has been discussion of the benefits of speech recognition technology to serve the vocational needs of persons with severe disabilities, the technology has not begun to serve all those who could potentially benefit from it. With the introduction of large vocabulary speech recognition technology in 1985, rehabilitation professionals anticipated very optimistic results on the number of individuals who would return to work [2]. Although many individuals acquired or purchased expensive technology, only a small percentage of those individuals who received speech recognizers are currently employed. Part of the problem lies with the fact that the technology has not been ready for distribution to individuals who are quadriplegic. In part, it has been impossible to predict based on client profiles, which individuals stand the best chance of vocationally succeeding with the technology. This problem is due to the fact that little systematic or thorough clinical reporting has been published in the rehabilitation literature.

Another important part of the problem is the fact that speech recognition is slow. The focus has been that individuals who are disabled are now able to do something they were not able to do before through the use of speech recognition. However, consider the employer's perspective. The employer wants a cost-effective and productive employee. Computer based jobs involving documentation or software operation can be objectively and quantitatively evaluated in terms of an individual's productivity. One parameter the employer needs to consider is text creation rate. The job the employee holds, whether it be computer programmer, receptionist, administrator or social service counselor, is required to create text to complete the job.

Large vocabulary speech recognition technology is a severely rate limited way to create text. Few papers are reported in the literature which systematically study and report text creation rates with current speech recognition technology. Antectdotal reports claim text creation rates of 15 to 40 words per minute, depending on the nature of text being created; creating new text takes longer than creating memorized text. Comparing the rates of users of large vocabulary speech recognition to able-bodied typists makes it difficult to argue that speech recognition technology permits individuals to produce on the job in a competitive manner. At the high range of the scale, able-bodied typists are able to create text at approximately 100 words per minute. Court recorders who use a special method of keyboarding are able to type at approximately 150 words per minute while conversational speech ranges anywhere between 150 to 300 words per minute [3]. If the employer is under the illusion that speech recognition will be fast because speech is fast, this may result in an initial enthusiasm for the prospect of hiring an individual with severe writing impairments. However, without appropriate counseling from a rehabilitation service delivery team, the employer may become disappointed after comparing the productivity results of the speech recognition user to the keyboard user.

There are instances where users report that use of a speech recognizer results in faster documentation than traditional methods of text creation. Emergency medicine physicians, radiologists and pathologists report a dramatic decrease in the time it takes to generate a written report by making use of special applications of speech recognition technology [4]. Here, the speech recognizer is used to access pre-stored blocks of text. Often referred to as voice-macros, these macros limit the amount of text that needs to be explicitly spoken, thereby increasing the rate of text creation. While creation of a large number of voice-macros (which can exceed 5,000 macros) is a time-consuming process, the resultant boon in productivity can be well worth the effort. Adopting the approach of job specific application development, we predict the potential of speech recognition in vocational rehabilitation can best be achieved within an appropriate clinical framework [1]. This paper focuses on one technology which permits job specific application development. Its utilization is illustrated through two case studies.

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[1] We use the term "knowledge engineering" in the sense that voice macros are created for highly repeatable blocks of texts, and these macros are hierarchically structured.

The speech recognition technology used in this model is the Kurzweil Voice Report system (the KVR) manufactured by Kurzweil Applied Intelligence Inc. (KAI, Waltham, Massachusetts). The KVR is built on three layers: (1) the large vocabulary voice recognition system that has functionally unlimited vocabulary size, is speaker independent/adaptive, uses discrete speech, and responds in real time; (2) the report generation software that takes care of the format of the reports the KVR generates; and (3) the domain-specific knowledge base that contains domain-specific vocabularies, and uses trigger phrases and fill-ins to achieve increased productivity with structure and flexibility. The trigger phrase is a word or a phrase you say to bring up a predefined block of text. This block of text might contain fill-in-the-blanks, or so-called "fill-ins". Trigger phrases allow the user to say very few words and yet produce large chunks of texts; "fill-ins" keep the trigger-to-text translations flexible. A knowledge base is a set of trigger phrases about a particular topic (i.e., domain).

## OBJECTIVE

The overall goal of our speech recognition rehabilitation program is to identify clients whose (potential) job will benefit from the utilization of speech recognition technology, to develop speech recognition applications specific to the job, to train the client, and to deliver the technology to the client so s/he can be gainfully employed.

Our first client, JEM, is a 50 year old architectural designer who was self-employed prior to his spinal cord injury in 1988. A C5 injury left him quadraplegic. Due to the sensory and motor impairments in his hands, he is no longer able to fill out detailed specification sheets, or to draft plans for a house; nor can he use a conventional keyboard. Before JEM was enrolled in our speech recognition rehabilitation program, he used a double arm sling to aid his writing. However, this resulted in illegible writing due to hand tremor. Furthermore, he could not do any precise drawing with the arm sling. Since JEM's speech is clear (although somewhat slow due to vocal cord injury), he was enrolled in our speech recognition rehabilitation program. JEM's rehabilitation goal is to be self-employed again with the aid of assistive technology.

Our second client, HK, is a 43 year old vocational rehabilitation counselor with the state vocational rehabilitation agency, who was diagnosed with multiple sclerosis in 1979. She can barely hit the keyboard with her left hand, and she can't control her right hand due to intention tremor. Her rehabilitation goal is to be able to document client meetings and phone conversations in a timely fashion using her voice as computer input so that she can retain employment.

## APPROACH

The approach we take for each client is somewhat different depending on the individual's disability and the job requirements. For JEM to be gainfully self-employed as an architectural designer, he has to produce (1) detailed written documents (i.e., contracts, specification sheets, material lists, etc.); and (2) architectural drawings with varying degrees of detail (i.e., floor plans, cross sections, etc.). JEM's rehabilitation program involves three phases: (1) using voice recognition technology for document production; (2) using voice recognition technology together with other means of input devices (e.g., head-mounted pointer) to operate CAD software to produce architectural drawings [5]; and (3) system integration. We've finished the work for the first phase and the results will be reported in the next section. The second phase of the project is well under way. Our plan for the second and third phases of the project will be presented in the discussion section.

HK's rehabilitation program is essentially the same as the first phase in JEM's program.

## RESULTS

All our training on the KVR was done in a noisy office environment, where people come and go and have meetings. The recognition rates were greater than 90% for both JEM and HK. We believe that this high recognition rate can be maintained when JEM uses his KVR at home or when HK uses hers in her office.

JEM has received over 100 hours of training. The domain-specific knowledge base developed for him allows him to produce documents. The KVR allows JEM to produce professional-looking documents efficiently. It takes JEM 7 minutes to complete a 2-page specification sheet and print it out on a laser printer. According to JEM, it used to take him 40 minutes to fill out the same spec sheet by hand prior to his spinal cord injury. Post trauma, it would take him up to 2 hours to finish the same work and his handwriting was only legible to himself. We estimate that it will take JEM approximately 2 hours to dictate and format the same form word by word using a conventional large vocabulary isolated word recognition system.

Due to his vocal cord injury, JEM's speech is slow and changes over time. We have observed that after 2 or 3 hours of continuous speaking, JEM's speech is even slower[2]. His intonation changes as he struggles to utter words. With the voice-macros we've developed for JEM, he can produce documents well within the 2-hour limit during which he is in good voice.

HK has received roughly 20 hours of training. The KVR has been demonstrated to benefit HK. In addition to being able to access a computer through voice and to produce documents very efficiently with trigger phrases, HK also benefits from cue text[3]. HK is required to put codes next to almost everything she documents. While she remembers some of the most commonly used codes, she has to look up other codes because HK also suffers from memory deficit. Given the mobility impairments with her hands, this is both cumbersome and time-consuming. With the KVR, we have incorporated code lists in cue text, so HK can see the codes next to their meaning, and be able to select one without going through her files.

## DISCUSSION

We've began phase two of JEM's program which involves: (1) training JEM to use AUTOCAD software, and (2) developing necessary software so JEM can access AUTOCAD through voice and/or head-mounted pointer [5]. Phase three of JEM's program is system software/hardware integration. We first became aware of this issue when we moved from phase one of the project into phase two. At that time, the KVR software only ran on a 386-PC while AUTOCAD ran on both the 386- and 486-PC. The question was what type of PC should we recommend to JEM. We later found out that the KVR system

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[2] It was objectively and quantitatively determined to take him twice as long to pronounce a word compared to a person without vocal cord injury.

[3] Cue text is associated with "fill-ins". It is displayed on computer screen during dictation of documents, but does not enter the final print-out of documents.

also runs on a 486-PC. The 486-PC was chosen. In JEM's case, sophisticated software and hardware are needed in order for him to perform at a competitive level. We need to be aware of software and hardware compatibility issues from the beginning. In planning for system integration, we also asked JEM to draw a floor plan of his office/drafting area in his house (JEM will be working at home), so we can begin to plan how to position equipment into his work space, and whether further modifications to his house will be required.

For HK, we will continue to implement additional forms. We have finished work on the "initial interview form", and have begun working on "certificate of eligibility", "fiscal contact report", and other forms.

Reliable large vocabulary voice recognition technology is still new and very expensive (>$8,000). We chose the KVR system because it increases productivity dramatically through knowledge engineering. We believe that in order for a person with a disability to be gainfully employed, s/he needs to perform competitively compared to other people in the work place. As long as the technology is well supported and has potential for further development, it should be demonstrated to be cost-effective to use.

The issue of maintenance and customer support arises whenever high tech is involved. Given the sophistication of the KVR and AUTOCAD software, JEM can not be expected to solve all future problems as he might encounter. Thus it is essential to have an adequate plan for his continuous support long after the technology has been installed and after his case is closed in our program. We have worked closely with customer support at KAI and have reason to believe that their customer support team will adequately support JEM. During the second phase of our program, we need not only to train JEM on CAD, but also to establish adequate long-term technical support for him on this technology as well.

Psychosocial and medical aspects

In a rehabilitation program that involves high tech training, the engineer deals with the client most of the time. However, the engineer might not be aware of all the medical and psychosocial aspects about the client which we believe are important to the success of technical training as well as the client's future success. Our program includes on its team engineers, a clinical/research psychologist, a speech scientist, and a physiatrist, who work together to promote the well-being and success of our clients.

Before JEM started his training on the KVR system, the engineer was aware of his short-term memory loss and was able to employ strategies and utilize features in the KVR to provide cues to guide him through dictation. An intensive training was done right after JEM was introduced all the basic features of the KVR. It proved to be quite effective.

As the training went on, it was noticed that JEM often went astray during conversation and would go on a tangent and not return to the topic. JEM appeared to be manipulative in negotiating equipment needs. The psychologist discovered that JEM's lack of focus was due to minor brain injury. Therefore, he was not able to suppress random thoughts in the midst of conversation.

It was also observed that JEM seems to feel that the more equipment we recommend, the more we support him. He fears losing the emotional or technical support from our program. When we recommended that the computer monitor and the monitor for his VisualTek device be combined so only one monitor needs to be purchased, JEM insisted that he get two monitors. JEM apparently has difficulty letting go any equipment he wants to get. This will be negotiated with JEM's state VR counselor and JEM to suit both party's needs.

When the engineer who worked with JEM for the first phase of the project noticed something unusual when the phase came to a close, our clinical psychologist was able to point out the difficulties some clients have with termination of any kind. Thus it was made clear to JEM that he will receive continuous reinforcement training from the engineer as he moves into the second phase of the project. This helped JEM focus on the work again.

We have spent much less time working with HK and are only beginning to discover her psychosocial and medical aspects. HK is currently working and uses a computer at work site. She fears that learning to use the KVR at the same time will cause confusion on her job (due to her cognitive limitations). We'll need to evaluate her concern and when necessary, work out strategies to help her better cope.

JEM and HK are both highly motivated individuals who expect our speech recognition rehabilitation program to contribute to their gainful employment. Productivity is key to their future success. With the KVR system and knowledge engineering, we have been able to provide both clients with a document production tool that allows them to produce professional reports in far less time than with conventional speech recognition systems.

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Address correspondence to:
Hong Z. Tan
Rehabilitation Medicine
75 Kneeland Street 5th floor
Boston, MA 02111

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# A MODEM-ACCESSIBLE FREE-FORM DATABASE FOR ASSISTIVE TECHNOLOGY INFORMATION AND REFERRAL

Naama Zahavi-Ely
Virginia Assistive Technology System
Richmond, Virginia, USA

## ABSTRACT

Text database may provide a unified, intuitive front end for large-scale comprehensive Assistive Technology information collections. Such a database can combine data of varied kinds from different sources. A comprehensive text database of Assistive Technology available free of charge via modem can enhance public access to Assistive Technology information, both directly, and indirectly by enhancing the information resources of service providers and information providers. This presentation discusses the design and implementation of one comprehensive on-line text database.

## BACKGROUND

Information on all levels is identified as a major need in the mandate of the Tech Act-funded state projects. Service providers as well as users and their families need information about devices, manufacturers, vendors and prices; about funding sources; about assessment, training, equipment loans, repairs, support groups and more. Such information must be comprehensive, detailed, up-to-date and easy to find.

At the present time much of this information exists, but it is spread over a large number of local or specialized information centers, databases and directories. Learning where to find information on each subject becomes a highly skilled job. Even when the information is available, it is difficult and laborious to ferret out and collate the information needed by an individual client. Itinerant service providers, case managers, and counselors in remote locations may not have any easy access to information collections.

Some databases, like Abledata, are available via BRS; but BRS database searches are cryptic, and fees are so high that consumers are largely excluded and even service providers have difficulty covering them. HyperAbledata requires CD drives which are not readily available to the average service provider or information and referral agency, let alone the individual consumer. The Service Delivery Directory (SDD) will be of help in the area of services, but may not be readily available in all locations for some time. All such distributed databases require conscientious effort on the part of their users to acquire updates.

## STATEMENT OF THE PROBLEM

Stand-alone information centers
The usual solution to information needs is to establish an 800 line where people can call an information specialist who searches and finds the information for them. Such an approach has the advantage of being readily available and of providing personal help. But if care is not taken, this approach by itself can easily result in the creation of a multitude of small information centers, each trying to cover all fronts, and each needing to create and maintain information collections, manual or computerized, all over again

Sharing information collections on-line
If, instead of creating a database for the use of a single information center, one could make the same database available to everyone on-line via modem, one would be enhancing the effectiveness of that database significantly. Instead of being available in one or (if distributed) in a small number of centers, the information is directly available to anybody who has a computer and a modem -- a large and growing population. Maintenance is required in one location only. Service providers and experienced consumers would be able to search for information any time of day or night. The information specialist would be able to concentrate on helping people who need person-to-person assistance. Many information agencies and support groups would be able to access the on-line database for their clients as needed, rather than sending them on another round of calls; and resourceful people, whether users, family, friends or service providers, would be able to browse and find information with an "I'll know it when I see it" approach which is impossible when working through an information specialist. An on-line database can never take the place of personal assistance; but it means that personal assistance can take place at many locations rather than one, and is a help rather than a barrier.

## RATIONALE

Information collection issues
An on-line database must be comprehensive, detailed and easy to use to be effective. Collecting comprehensive data from scratch on a scale large enough to be useful is clearly beyond the scope of most information centers. Nor is it efficient to duplicate information-collecting efforts. An alternative approach would be to share and distribute existing collections of information. There are many of these in easily-duplicated computer format, whether as a database, or as a word-processing file, or in print which can easily be scanned into a computer.

The problem then becomes one of accessing the information. Existing collections make use of many different programs -- databases and word processors -- and many different hardware platforms, including PC's, minicomputers and mainframes. Most of the software is not user-friendly, and most word-processing software is not meant for complex information searches. Even if one could obtain many computer information collections in their native formats with their original software and make them available on-line from one location, navigating between the databases and learning to use each in turn might become an ordeal, and keeping the data intact and safe from mistakes of naive users would be a nightmare.

Combining diverse information collections into one
The alternative is to combine data collections from many sources into one structure. Combining such diverse information into a single structure using traditional database technology would be extremely difficult and not necessarily very rewarding. One would have to know or guess in advance all the data

structures one would want to accommodate. The varied nature of the information itself would make that task difficult, and the need to accommodate diverse and variable field lengths and diverse linkages would complicate the issue. In addition, most databases are not particularly user-friendly without the creation of a superstructure of menus and interfaces closely tailored to the files, which again would necessitate knowing in advance the structure and contents of the information collections one would use. To add insult to injury, the strict field structure of most databases would not really be helpful in an Assistive Technology information collection. Knowing the terms to search for is enough of a challenge without having to figure out in which fields to search for them.

Text database as an information retrieval tool
Text database software can answer many of the information retrieval needs. Such software can search large volumes of text for words, phrases or boolean combinations of words or phrases, without regard to the structure of the records involved. Records from via modem any database, no matter what its structure, can be transferred into a text database and searched successfully; all one has to do is translate any codes into English, a job that can easily be done by a simple computer program. Such a text database can include records that originate in many different databases or word processing documents -- or, for that matter, in printed information scanned into files (fact sheets, printed directories and the like). There is no need for the records to conform to one fixed structure.

On-line database constraints
A public on-line information system should not place unnecessary barriers before its users. It should not demand that callers have any special hardware or software, or special computer know-how beyond the basics needed for any remote computing. It should assume that callers will probably not have high-end equipment. At the least, one should be able to access the system from IBM PC and compatibles, Macintosh and Apple II computers. As far as possible, the system should be designed to be usable with letter and number keys only, without function or control keys which may not work properly across communications protocols and between differing hardware.

Remote computing, graphics and adaptive equipment
The need for remote communications prevents the use of graphics. Even with the best equipment, transmitting graphics screens via modem makes for exasperatingly slow computing. In addition, most callers would not have the same kind of display equipment; even within the IBM PC family, callers might not have VGA display. As a result, a public on-line database should be limited to ASCII text only.

The need for clean ASCII text display and simple letter and number commands squares neatly with the use of alternative input and output. People who use adapted equipment would be able to access the information via modem from their own computers, which are tailored to their needs and familiar to them. This would benefit disabled counselors and service providers as well as persons calling for their own needs.

## DESIGN

Text database software
The text database for our system was selected according to the following criteria:
Capacity. The ability to handle very large amounts of text without speed degradation.
Ease of searching. Clear, non-cryptic command structure, with easily modifiable searches; a clear indication of the number of items found by each search, so that the caller can choose whether to modify the search further; the ability to use wildcards.
Ease of use. Clean, predictable text display, without graphics; ability to run with letter and number keys only, without function or control keys.
Customization. Modifiable help and menus, thesaurus and noise-words list.
Data maintenance. The ability to handle information in varied format -- no requirement for a unified structure; the ability to add information with little effort and minimal conversion.
A survey of existing text databases pointed to ZyIndex as a good candidate for our purposes.

Communications software
The communications software had to be able to accommodate a variety of callers' equipment. In addition, it had to be able to capture and transmit correctly direct screen writes which are used by ZyIndex. PcAnywhere running in host mode answered these criteria. It can be set to start automatically and reboot the computer between calls for smooth operation; it can disable Ctrl-C and Ctrl-Break for security. It can print to the caller's printer. Both remote and local keyboards can be active, so that long-distance tutorial sessions can be arranged.

## DEVELOPMENT

Data sources
Generous sharing by information centers provided us with preliminary data for our database. As of January 1992, the database contains information from Abledata, the Seaside database, the IBM National Resource Center for Persons with Disabilities, and the Richmond United Way Human Services database. We hope and expect to receive information from other existing databases and to collect local information.

Data conversions
ZyIndex handles information in file units. We split the information we received into small text files, each containing one record. The first 60 non-space characters of each file are displayed by ZyIndex as a comment; therefore we made sure the first line of each record was indicative of its contents -- usually the product's name or generic name. We converted any codes to English, and added to each record a note of where it came from and when. The conversions were done by computer programs. Once a data conversion program is written for a particular source of information, it can be used again with updated information from the same source.

Modifications and setup
We modified the ZyIndex menus, the noise-words list and the thesaurus. The on-line help within ZyIndex was modified to suggest search strategies using Assistive Technology questions as examples. The data were run through the ZyIndex indexing program. Menus, log files and help screens were created to come up automatically when users dial into the on-line computer. Callers can search the database, print either at their computer or to a file they can download, and leave messages for the information specialists. We made the system as clear and easy to use as we could.

State of the system as of January 1992
As of January 1992, the on-line text database is available to the public on a trial basis. It runs on a single 386 PC with a 650M hard disk. It contains a comprehensive collection of data on Assistive

Technology devices and some information about services -- over 13,000 records in all. The system can run unattended and checks its own integrity upon rebooting between calls. Any person may call and use the database, one at a time. We ask, but do not require, that callers fill out an on-line questionnaire upon logging off. The database as it stands now is already useful to many, and we expect to keep adding information to it. By its formal opening in March 1992, the database will be installed on a LAN to provide access to several users simultaneously, locally or through 800 modem lines. The database will also be used locally by an information specialist answering phone, mail and walk-in queries.

Data collecting prospects
The project is making several data collection efforts. The SDD software will be used to collect information on services on the state and local levels. Others have undertaken to collect information on funding streams. In each case the data will be available to the public both in their native format and in the on-line database. We are looking for other information centers that would be willing to share data with us; areas of particular interest are demo sites, equipment loan or rent programs, product comparisons, peer and family support groups, and user tips.

## EVALUATION

Using the on-line database
So far, users seem to find the system intuitive and easy to use. Callers start out by specifying words or phrases to search for, with wildcards if desired. Within a few seconds, ZyIndex displays the number of items (records) that contain the desired words or phrases. If the number is large, as frequently happens, the user will probably elect to modify the search until the number of items found looks reasonable. The caller then selects to display the information, getting a list of file names and comments. One can go up and down the list and select any record of interest for full display. The words or phrases searched for are highlighted on the screen, making it easy to see at a glance whether a record indeed contains the desired information. There are usually some false hits -- a person looking for van modifications might get an unrelated item manufactured at Van Nuys, CA; but such cases are easy to spot and skip over. The searching is usually very interactive, with the callers shifting back and forth between specifying terms to search for and browsing the information found. As a bonus, people are likely to encounter items they were not looking for, but which turn out to interest them very much.

Communications issues
We wanted to create a system that people could access from a variety of software and hardware. As of January 1992, this objective is partially achieved. Callers using PcAnywhere/remote have full use of all features of the database, with good quality display. Callers with other hardware or software may experience some display or keyboard difficulties. Lack of function or control keys is not a problem, as practically all commands can be given by letter or number keys. Callers who lack cursor keys may not be able to view the bottom part of longer records. Luckily, most records fit on one display screen. The screen does not always clear properly, which affects the menus (the information display itself is usually clear). We are trying to solve these problems in time for the public announcement of the on-line database in March 1992. Even in its current state, the on-line database is usable by callers employing a variety of hardware and software combinations, and already contains enough information to make accessing it desirable.

## DISCUSSION

The best way to assure a reliable and comprehensive coverage of a given area is to have the information collected by a specialist in that technology, disability, service or geographic area. Specialists need to collect such information anyway in the normal course of their work. Effective information dissemination, however, calls for the collected information to be available in many locations rather than one, and as one or a few bodies of information rather than as many narrow, super-specialized collections.

Some centrally-coordinated collaborative efforts can be carried out on the collecting end -- Abledata is a good example, and we hope the SDD will become another. By contrast, a text-based database is not intended for primary information collection. Rather, it is a tool for combining information collected by other methods and making it easily searchable. Making the information available to the public by modem requires one to develop relatively intuitive search methods rather than rely on the information specialist's training and skill. It can benefit information collectors by making their information widely available with minimal effort on their part. As in all computer-disseminated information, one needs to be careful of data ownership, acknowledge the information sources and collectors, and obtain permission for any copyrighted material.

Hosting a text-based database as described here does not call for specialized computer equipment. A larger-than-usual hard disk is desirable but not required. One could use a single desktop computer, for one user at a time; the use of a LAN can create simple and expandable multi-user access. It would be easy to create identical or similar systems, either to combine information from diverse sources (as in our case), or to provide alternative access to an otherwise forbidding database.

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Naama Zahavi-Ely
The Virginia Assistive Technology System
4900 Fitzhugh Avenue, Richmond, VA 23230
(804) 367-2445

# NORTH CAROLINA'S ASSISTIVE TECHNOLOGY INFORMATION AND REFERRAL NETWORK

Lawrence H. Trachtman[1], Michael C. Sharp[2] and Susan A. Valiquette[2]
1 North Carolina Assistive Technology Project
2 Family Support Network of North Carolina

## ABSTRACT

In response to Public Law 100-407, North Carolina has developed a statewide assistive technology information and referral system. This service combines the resources and expertise of two existing programs to help match consumers', families' and providers' needs with information about assistive technology devices and services. A seven-step process was used to implement the network, the key feature of which is regional electronic information sharing and computer data base access. Results to date indicate the service is being used with positive outcomes and that initial expectations are being met.

## BACKGROUND

The passage of Public Law 100-407 (the "Tech Act") has necessitated that states develop consumer responsive systems for assistive technology services. In order to address their citizens' information needs, each of the 31 states funded under Title I has responded with an information and referral (I&R) system unique to its own characteristics (social, economic, geographic and others). Here in North Carolina, we have implemented a statewide network for responding to assistive technology information requests. This network is modeled after a similar program in South Carolina called Access Technology (Trachtman and Wiles, 1989). The key feature of the North Carolina system is that it uses the resources and expertise of two existing programs to help match caller's needs with information about assistive technology devices and services. In addition, the network provides for statewide electronic database access, a relatively new feature for I&R systems. This paper will describe the process of developing and implementing North Carolina's I&R network, and offer considerations for other states' I&R system planners.

## OBJECTIVES

Initial planning for North Carolina's assistive technology I&R system took place during January and February, 1991. Staff from the North Carolina Assistive Technology Project (NCATP - the state's federally-funded Tech Act program) developed the following eight system goals:

1. Provide toll-free telephone access to information about assistive technology products and services for consumers with disabilities, families, providers and concerned others throughout North Carolina.
2. Provide reliable, up-to-date information that responds to the caller's needs and is presented in a format acceptable to the caller (e.g., over the phone, TDD, hardcopy, braille, large print, etc.)
3. Provide multiple access points to I&R services and for varying levels of user sophistication (e.g., mediated/unmediated, call-in, computer dial-up, walk-in, etc.) and accessibility needs.
4. Avoid duplication of services by using existing resources whenever possible in the system's set-up and implementation.
5. Develop a system that responds to persons' with disabilities and other potential users' I&R needs, and which can be regularly evaluated for its effectiveness in meeting these needs.
6. Develop a system that can adapt to changing user needs and new information technologies.
7. Plan for a system that can be financially supported long term.
8. Maintain contact with assistive technology I&R programs regionally and nationally and encourage information sharing so as to stay current with trends in the field.

## APPROACH

A seven-step process helped implement the above goals.

1. Establish Collaboration
After evaluating existing I&R resources in the state, we decided that the system goals could best be met through a cooperative arrangement with the Family Support Network of North Carolina (FSN). The FSN is part of the Community Pediatrics Division in the UNC School of Medicine, Chapel Hill. It was created to help meet the needs of families with premature infants or children with developmental disabilities, behavioral disorders or chronic illnesses as well as the professionals who work with them. The FSN now serves as North Carolina's Central Directory of Resources (CDR) for Public Law 99-457 (Sharp et. al., 1989). The CDR is a computerized data base that gives families and professionals easy access to information about specific disabilities, services, agencies and other resources for children and adults with special needs and their families. Recognizing that the FSN had an existing computerized data base of services, and that it was already operational and recognized statewide, the NCATP set up a collaboration with the FSN to provide assistive technology I&R services.

2. Update Services Taxonomy
The central directory, maintained on a Sun minicomputer located at the FSN, uses the Infoline taxonomy (Sales, 1991) to classify services and search the data base. Although many other state's assistive technology I&R programs were considering using the taxonomy being developed at the Trace Center (Vanderheiden, 1991), we decided to stay with Infoline. Infoline is a complete human services taxonomy, and by using it we would also speed up our development process. We did, however, incorporate Trace's assistive technology classifications into new Infoline codes. The latest version of Infoline has in fact been updated to include these assistive technology classifications.

3. Collect Provider Data
In April, the CDR was updated to include assistive technology service providers in North Carolina. A cover letter, data collection instrument, coded checklist of devices and services, and self-addressed stamped return envelop were mailed to 515 potential technology providers. These included therapists, rehabilitation centers, state and community agencies, and other specialized programs. Almost 50 percent (256) of the surveys were returned and entered into the data base. There are currently 22,000 total entries (including service providers and information resources) in the central directory.

4. System Design
North Carolina's assistive technology I&R network is designed to utilize the existing resources and expertise of both the NCATP and the FSN (Figure 1). Primary access to the network is provided through the FSN's toll-free telephone number (although many people still call the NCATP directly). Using the central directory, trained FSN counselors help identify services and other resources appropriate to the caller's needs. Most requests (called an *encounter*) are answered over the phone and, if needed, information materials are mailed out. When a request cannot be answered by FSN staff, it is referred electronically to one of the NCATP's four regional technology specialists. These staff, located in Greenville, Raleigh, Winston-Salem and Charlotte, can each connect via computer and modem to the FSN's data base in Chapel Hill. An electronic mail message alerts the NCATP staff member to follow-up with a technology-related call from their region. Necessary background information, such as disability and technology need, is recalled from the initial encounter in the central directory. Using comprehensive print and electronic resources, the NCATP specialists are better able to respond to more difficult assistive technology requests. In addition, regional interdisciplinary teams provide back up technical assistance to the NCATP staff. The completed encounter is then logged directly into the central directory and transferred back to the FSN for record keeping and reporting.

5. Staff Training
NCATP and FSN staff trained each other on their respective parts of the I&R system. For FSN's staff, it was an opportunity to learn more about the NCATP, assistive technology terminology, products and resources. NCATP staff learned about the FSN, how to log into the central directory, conduct searches and use electronic mail. We anticipate ongoing training needs as system changes are made and new questions arise.

6. Public Awareness
Initially, promotion of the I&R service was limited while development and training were taking place. Both the NCATP and FSN listed the toll-free telephone number in their new brochures which are regularly distributed. In addition, articles were placed in each program's newsletter and also submitted to other relevant publications across the state. Staff routinely include information about the new service in presentations to professional and consumer groups statewide. We are currently planning for more widespread promotion as the system becomes fully operational.

7. Reporting and Evaluation
At present, both the NCATP and the FSN record caller information and generate quarterly reports. In addition, each program mails out an evaluation form to callers which asks about their satisfaction with the service and any comments they may have. We are planning to consolidate the record keeping, reporting and evaluation functions as system usage increases and more calls come in directly to the FSN through their toll-free number.

RESULTS

The NCATP recorded 390 technology-related requests from February through November, 1991. The primary reasons for contacting the NCATP are shown in Figure 2. Figure 3 shows the breakdown by caller type The assistive technologies requested by callers are shown in Figure 4. The majority of the NCATP's calls are for product information (251 requests), followed by general project information (77), consultation/technical assistance (75), referral to other resources (69), funding assistance (69) and

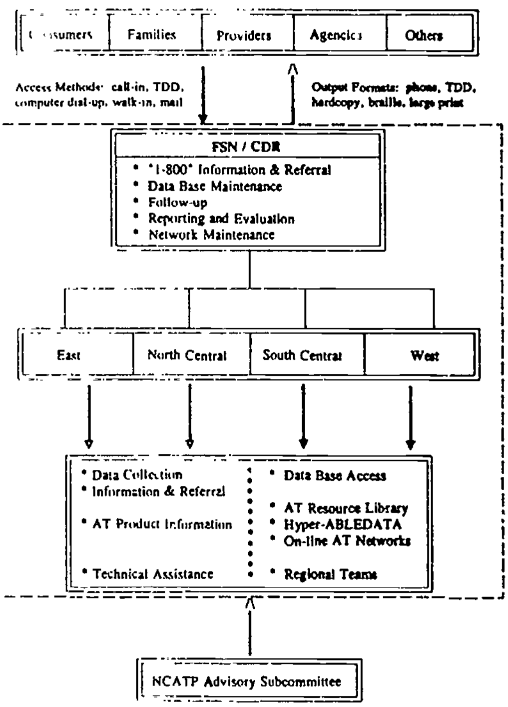


Figure 1
Information & Referral System Design

specific assessment/recommendations (61). The collaboration with the FSN officially began in July. Through September, the FSN received 56 technology-related calls. This was approximately 10 percent of their total number of calls (549). Of these 56 calls, between 15 and 20 were referred to the NCATP's regional staff for further assistance. Forty eight percent of the FSN's total number of callers were professionals and almost 40 percent parents or other family members. These figures closely match the NCATP's caller profile (see Figure 3).

DISCUSSION

We have found many benefits in the approach described above for establishing a statewide assistive technology I&R service. First, by combining the resources of two existing programs, we were able to expedite the system's development. This included not only the physical resources, such as a computerized data base, service taxonomy and toll-free number, but the two programs' respective expertise as well. Second, the electronic, computerized network linking the NCATP's regional offices with the FSN represents a new and exciting feature for I&R systems. Through this network, staff can communicate electronically; but more significantly, each program has simultaneous access to the data base. This allows for multiple points of information retrieval as well as entering new data and updating existing records. Thus, regional staff can enter data for new local providers they have identified, and this information immediately becomes available to the FSN and all other regional offices. We feel that this aspect of North Carolina's system truly captures some of the advantages

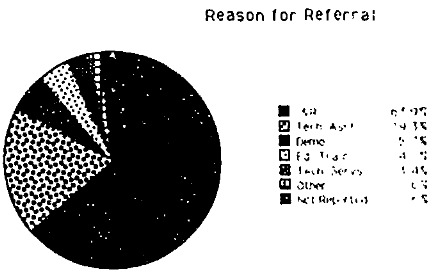


Figure 2

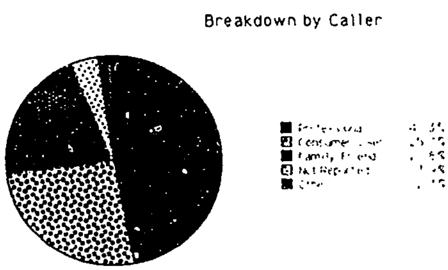


Figure 3

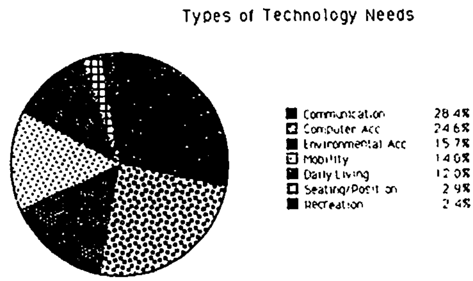


Figure 4

offered by today's information technologies. Finally, the current system design provides flexibility for growth and expansion as new needs emerge. We are already considering adding an electronic bulletin board onto the network for further information sharing, especially among consumers and families.

This development project has not been without its challenges, however. As always, data collection remains a major undertaking for I&R systems, both initially and for updates. Significant commitment of staff time and other resources is essential to ensure reliable, up-to-date information in the data base. Although we feel confident with our initial data collection effort, we realize that many assistive technology providers were likely missed and that continuous updates will be needed. Second, the logistics of setting up electronic connections to the NCATP's regional offices has also been challenging. Ordering computer hardware, installing phone lines and providing staff training all took slightly longer than expected. In addition, the FSN made a major upgrade to both its hardware and software during this period which caused a delay in bringing NCATP staff on-line. However, these needed upgrades will help overall system performance and provide for future expansion as described above. Third, publicity and promotion represent a catch-22 for new systems like ours. While wanting to let people know about the service, you still don't want to overload newly trained staff who are using limited data. We have used existing channels to reach audiences already familiar with our programs, and we hope to soon expand our promotion efforts to include other potential users. Finally, we are still consolidating the data collection, reporting and evaluation systems initially maintained by the two respective programs. When completed, we hope to have only one, computerized record keeping system. This will provide us with quick and accurate analysis of relevant caller data.

Overall, we feel this project has successfully met our initial goals. Although relatively new, the system provides a solid foundation for delivering quality assistive technology I&R services in North Carolina. In addition, by taking advantage of current trends in information technology, expansion to meet future consumer needs should be readily achievable.

## ACKNOWLEDGEMENT

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Lawrence H. Trachtman
North Carolina Assistive Technology Project
1110 Navaho Drive, Suite 101
Raleigh, NC 27609

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# The University at Buffalo Rehabilitation Engineering Center's Consumer Assessments Project

William C. Mann, OTR, Ph.D., Jurgis Karuza, Ph.D., Edward Steinfeld, D. Arch., Dianne Hurron, RN, M.S.
University at Buffalo - SUNY

ABSTRACT

The Center for Therapeutic Applications of Technology at the University at Buffalo, in collaboration with other major university based centers, professional associations, and New York State agencies, initiated work on September 1, 1991 on the NIDRR funded *Rehabilitation Engineering Center (REC) on Assistive Technology and Environmental Interventions for Older Persons with Disabilities*. The lead research project for the REC is a needs assessment study called the *Consumer Assessments Project*. This project provides information about persons over 60 years of age, on the nature of their disabilties, assistive device use, their living environments and social support systems, and quality of life indicators. This paper provides an analysis of the results of the first 200 subjects interviewed in the Consumer Assessments Project.

BACKGROUND

Current information regarding the effective delivery of assistive technology and environmental interventions to older persons with disabilities is insufficient. What are the major disabilities of older persons? What functional deficits comprise these disabilities? What "handicaps" result from barriers in person / environment interactions? How do older persons compensate for disabilities in different environments? The Consumer Assessments Project systematically explores the interactions between older persons, their environments and assistive technology. This background section explores the current state of knowledge on the elderly and its relation to the Consumer Assessments Project in the following areas: (1) disability; (2) environmental interventions; (3) assistive technology; (4) well being and quality of life and (4) care giver factors.

Disability:

There have been several national surveys over the past decade examining limitations in the activities of daily living (ADLs) of the elderly . These include: National Long Term Care Survey (1982 and 1984); National Health Interview Survey (1984); Longitudinal Studies of Aging (1984-86); National Nursing Home Survey (1985); National Medical Expenditure Survey (1987). These studies have demonstrated that somewhere between 5 and 8 percent of persons over 65 years of age require assistance with at least one ADL. For institutionalized older persons, over 90 percent require assistance with at least one ADL. The two most frequent limitations occur with bathing and dressing.

Environmental Interventions

Both quality of life and health vary with the type, location, and condition of housing and the degree of age segregation in the immediate neighborhood.[1] The level of environmental stimulation and challenge in the "micro-environment" contributes directly to physical and mental health.[2] The design of the micro-environment (homes, rooms, spaces, corridor systems, etc.) affects the pattern and maintenance of social behavior.[3] The micro-environment has a direct impact on independence in activities of daily living and also on security and safety.[4] The physical environment has been recognized both as a major object of effective behavior and also as a structure within which control and autonomy can be realized.[5] Three general observations can be made about the research on aging and environment that pertain to the goals of the Consumer Assessments Project. First, without some understanding of an individual's environment, it is difficult to know if changes in functional ability are the result of actual changes in health status or changes to the environment. Second, the spatial behavior of older people can tell us much about how successful a person has been in achieving control and autonomy. Third, housing and neighborhood conditions must be examined as contributors to functional ability and life satisfaction. These observations are operationalized in the Consumer Assessments Project by collecting data and examining research questions related to two sets of variables: 1) the degree to which the living arrangements and neighborhood restrict the activities of older people, 3) the degree to which individuals use and manipulate the environment.

Impact of Assistive Technology on Older Persons

There have been very few reported studies of the current use of, or need for, assistive devices by elderly persons. Labuda in his recent review states:" *At this time, there is no empiric evidence that technology intervention will either reduce health care costs or allow a person to maintain independence for extended periods of time while reducing the need for human intervention.... Given the changing demo*

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[1]Carp, F. (1987). The impact of planned housing. In V. Regnier & J Pynoos (Eds). Housing the aged. NY: Elsever.

[2]Lawton, M. P. & Nahemow, L (1973). Ecology and the aging process In C. Eisdorfer, & M. P. Lawton (Eds.). Psychology of adult development and aging. Washington, DC: APA.

[3]Lawton, M. P. (1978). Sensory deprivation and the effect of the environment on the management of the Senile Dementia patient. Paper presented NIMH conference on clinical aspects of Alzheimer's, Disease and Senile Dementia, Bethesda, MD.

[4]Steinfeld, E. (1987). Adapting housing for older disabled people. In V. Regnier & J. Pynoos (Eds). Housing the aged. NY: Elsever.

[5]Steinfeld, E. (1981). The meaning of housing for old people. In J. Duncan (Ed.). Housing and Identity. London: Croom Helm

*graphics, and the social and economic demands for health care for the elderly today, not in the future, this is an area which warrants further serious investigation.* "[6]

A surprisingly large number of devices prescribed during inpatient and outpatient rehabilitation are found in the closet, not being used, months and years later. Page et al report that of 500 people with assistive devices, 50% were not used. One major interpretation of this observation is basically that the patient has not found the device to be useful.[7] There can be several reasons for non use. First, a device may have outgrown its usefulness because it served a training function; the assisted function has been restored sufficiently to no longer need the device. Second, the patient was not adequately trained in use of the device and he or she gives up trying. Third, the device does not do the job and/or the effort to use it is too great. Fourth, devices are sometimes cosmetically offensive for some people; they refuse to use them.

Well Being and Quality of Life

Measures of well being and quality of life of older persons with disabilities are relevant, in several ways, to understanding the coping process and the impact of assistive devices. First, well-being factors may be important moderating factors that can affect the rate of rehabilitation, the use of and the desire for assistive devices. Kemp lists several psycho-social factors that are predictive of rehabilitative effectiveness: motivation, including sense of achievement and mastery, cognitive ability, depression, and having a social support network.[8] Although there is a scarcity of data on how cognition affects the rehabilitation process, some studies suggest that cognitive disability makes rehabilitation less efficient.[9] Measuring well-being variables allows the identification of potentially important moderating variables which can enhance or retard the use of, and effectiveness of, assistive devices among older persons with disabilities.

Quality of life measures and well being measures of both the older person and care giver can also be powerful additional outcome indicators for evaluations of rehabilitation or assistive technology interventions. It would be expected that as individuals increase their ability they would have enhanced feelings of autonomy and control, life satisfaction, and self esteem.[10] Care givers, who would have less care giving burden, would have enhanced well being, although it is unclear if psychiatric syndromes and morbidities would necessarily improve.[11] An added benefit based on the work of Pruchno is that with less care giver burden and time spent assisting with ADLs the risk for institutionalizing the older person with disabilities would be reduced.[12] The Consumer Assessments Project measures several aspects of quality of life and well being.

Care Giver Factors

The current literature on care giving stress and burden suggests that assessment of disabled older persons should include assessment of the primary care giver (who frequently also is elderly and disabled). Studies suggest care giver stress and feelings of burden can predict institutionalization of disabled adults.[13] Kemp believes that the care givers faulty expectations and negative attitudes toward the older person with disabilities can impede their rehabilitation.[14] The number of ADLs predict the desire to institutionalize disabled older persons residing in the community.[15] The extent of care giver involvement and care giver stress can identify important risk factors for the institutionalization of disabled older persons. Care givers who are stressed are also at risk not only for reduction in their quality of life but also their physical health and psychiatric status.[16] Thus, changes in the functioning of disabled older persons by the use of assistive devices can have a direct effect: on the person with a disability and an indirect effect on the care giver, whose care giving burden is reduced.

## RESEARCH FOCUS

The purpose of this Consumer Assessments Project is to determine unmet and unknown needs of older persons for assistive technology and environmental interventions.

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6Labuda, D. (1990). Impact of Technology on Geriatric Rehabilitation. B. Kemp et al (Eds.) Geriatric Rehabilitation. NY: Little Brown

7Page, M. et al (1980). The problems of the selection, provision, and use of aids. In J. Bray, & S. Wright (Eds). The use of technology in the care of the elderly and the disabled. Westport, CT: Greenwood.

8Kemp (1990). op. sit.

9Kemp (1990). op. sit.

10Kemp (1990). op. sit.

11Schulz, R. et al (1990). Psychiatric and physical morbidity effects of caregiving. Journal of Gerontology, 45, P181-91.

12Pruchno, R., Michales, J. , & Potashnik, S. (1990). Predictors of institutionalization among Alzheimer's Disease victims with caregiver spouses. Journal of Gerontology, 45, S259-66.

13Zarit, S. Todd, P. & Zarit, J. (1986). Subjective burden of husbands and wives as caregivers: A longitudinal study. Gerontologist, 26, 260-66.

14Kemp (1990), op cit

15Pruchno, Michales & Potashnik, (1990) op. cit.

16Pearlin, Mullen, Semple, & Skaff (1990). Caregiving and the stress process: An overview of concepts and their measures. Gerontologist, 30, 853-94.

Consumer Assessments Project

This project will:

1. Identify special groups of older persons with major disabilities, determine their needs for and use of assistive devices and environmental interventions.

2. Develop a consumer assessment instrument that will combine existing and new knowledge on functional limitations, use of assistive devices and environmental factors from rehabilitation, medicine and related fields.

3. Maintain the REC sample of older persons and their care givers (consumer panels) who will be followed longitudinally to assess their changing needs over time.

4. Generate function, performance and environmental requirements for assistive device modification and development in related REC projects, and evaluate marketing strategies for the REC Dissemination & Utilization Programs.

5. Provide information on the priorities of environmental design research.

METHOD

Study Sites and Populations
Consumers have been (and continue to be) recruited from across the levels of care, ranging from hospital discharged patients to community based and institutionalized older persons. Subjects are referred from (1) discharged rehabilitation patient lists of five area hospitals; (2) contract organizations of the Office for Aging serving home based elderly persons; (3) Veterans Administration Home Based Medical Care Program; (4) Alzheimers Disease Assistance Center; (5) New York State (NYS) Commission for the Blind and Visually Handicapped; (6) the Center for Therapeutic Applications of Technology; (7) the NYS Office of Vocational and Educational Services for Individuals with Disabilities; (8) the NYS Office of Mental Retardation and Developmental Disabilities; and (8) three skilled nursing facilities.

Data Collection

Subjects are interviewed in their residence. A full time research associate conducts these interviews following a 47 page structured interview form. The following information is collected: demographics, physical health, activities of daily living, functional status using the Functional Independence Measure (FIM), mental status using the Mini-Mental Status Examination and the CESD Depression Scale, self esteem using the Rosenberg Self-Esteem Scale, locus of control using the Responsibility Scale, social resources, communication, use of supportive devices and prostheses, use of assistive devices, type and condition of interior (home or institution) and exterior (yard, neighborhood, community) living area. The interviewer also walks through the living area and rates the condition of the dwelling. When there is a care giver, he or she is interviewed using the Zarit Care Giver Burden Scale and the Shanas Health Self Report. The Consumer Interview takes approximately two and one half hours, and the care giver interview takes an additional half hour.

RESULTS AND DISCUSSION

The Consumer Assessments Project will be conducted over a five year period. In Year 1, 600 subjects will be interviewed. This paper will present an analysis and discussion of the results of the first 200 interviews. This includes three major groups of individuals: (1) persons with severe visual impairments; (2) persons (and caregivers) with Alzheimers Disease, and (3) persons receiving services in their homes through the Office for Aging service system.

This report will be primarily descriptive, and will make recommendations for areas of assistive device development and modification, and for environmental interventions

# THE APPLICATION OF ASSISTIVE TECHNOLOGY FOR THE INSTITUTIONALIZED ELDERLY

Carol A. Sheredos, P.T., Director, Meridian Rehabilitation Services and Lu Marletta, R.N., B.S., President Emerging Lifestyles, Inc.
Baltimore, Maryland USA

**Abstract**

A major challenge for today's health care industry is the provision of opportunities for the elderly, including those who are in institutions, to achieve their maximum possible quality of life. This should include state-of-the-art technological assistance and environmental adaptations. Ageism and funding issues will also be discussed.

**Introduction**

It should come as no surprise that America is getting old. Medical advances in this century have resulted in a ten-fold increase in the numbers of those persons who are over the age of 65, from 3.1 million in 1900 to over 31 million in 1989. By the year 2030, these numbers are expected to increase to 66 million, or 21.8 % of all Americans. The fastest growing segment of the entire U.S. population is the group over the age of 85, an age which, even ten years ago, would have been rarely reached.

Unfortunately, however, as age increases, so does the probability of pathological conditions and age-related disorders. Many older persons experience multiple disorders and physiological "system failure", resulting in some loss or decrease in functional abilities. This loss of functioning is often manifest in an inability to maintain independence in activities of daily living (ADL's), such as grooming, dressing, mobility, toileting, and feeding. Many of these persons are no longer able to function at home or in the community and are then admitted to nursing homes. The number of elderly in nursing homes is not insignificant: approximately five percent, or 1.5 million, are institutionalized for care in nursing homes, at any one time. The proportional percentage of institutionalized elderly increases with age, to 22 % of those persons over 85 years.

Nursing homes have historically been seen as "warehouses" for the elderly, even though more recently many admissions are relatively short term for convalescence and/or rehabilitation. The emphasis on rehabilitation, physical therapy in particular, has become part of routine long-term care only within the past ten years. Recent legislation (the Omnibus Budget Reconciliation Act of 1990) has brought attention to the need for restoration of maximum function to each and every resident; society, however, lags behind in its acceptance of these facilities as a center for such routine rehabilitation methods as encouragement in independent performance of ADL's and therefore the use of technology. Ageism has stunted the growth of assistive technology in the institutional setting.

**State of the Art**

The term "assistive technology" refers to the use of devices and equipment, or modification of such, to provide help to someone with a disability, or some difficulty in performing a task. Assistive technology is accepted practice in the rehabilitation armamentarium. Assistive technology may be either "Hi-tech" (such as robotics and computers) or "Low-tech" (such as walkers and adapted eating utensils). In any case, they are meant to allow an individual to manage his/her daily activities or living environment in order to remain as independent as possible. Many elderly persons in the community are users of assistive technology, perhaps without knowing so: hearing aids, eyeglasses, canes, telephone amplifiers, grab bars in the bathroom, and long-handled reachers, for example.

Assistive technology has found its way into the nursing home, to some extent: walkers, canes, wheelchairs, Geri-chairs, commodes and raised toilet seats, grab bars, patient lifts, and shower chairs are common. Often, however, the lack of adequate and safe equipment, the availability of such devices, and/or the lack of knowledge as to the appropriate prescription and use of adaptive devices results in ineffective or abandoned attempts to use ANY such devices. Additionally, false beliefs that institutionalized elderly are not able to learn to use, or do not have a life span long enough to warrant using, assistive devices, will only serve to stall efforts toward more extensive application of technology in these settings.

Funding for assistive technology in the nursing home is a major obstacle. Medicare will reimburse only on a very limited basis and only for those devices which are deemed "medically necessary"; state medical assistance programs will reimburse on a pre-approved basis only, a process which may take several months; facilities are faced with federal and state budget constraints and are reluctant to pour money into technological solutions (which may prove costly); families are also usually faced with their own financial constraints, including the high costs of nursing home care itself. Few third-party payors allow for reimbursement of adaptive devices and other technological solutions. Vocational Rehab is not a usual resource, as most nursing home residents are long retired and not vocational candidates. Some adaptive devices, modifications to environment or equipment, and other technology used to increase independent functioning, may fall under the services of Occupational or Physical Therapy and can be reimbursed under those disciplines (such as wheelchair seating solutions). In general, the clinician who recommends a technological intervention in restoring function to the institutionalized elderly MUST look into all possible resources, as no one funding source is appropriate in all circumstances.

**Directions for the Future**

Progress has been made in society's treatment of the nursing home resident: There is increased focus on rehabilitative services in order to assist the resident in regaining maximum functional independence; emphasis on patient rights preserves precious dignity so often lost in an institution; improved methods of care planning and supervision of care help to ensure positive outcomes. But the stigma of the nursing home and stereotypes of the older person persist. If assistive technology is accepted as "standard operating procedure" for other disabilities, why not for the elderly person in the nursing home who is struggling to hold onto as much independence as possible?

Suggestions for technological applications in the nursing home setting may include:
- Lighter materials in the construction of walkers, canes, orthotics, prosthetics, and shoes
- Improved devices for reaching, picking up, holding
- Improved wheelchair controls; appropriate wheelchair prescription
- Wheelchair seating and positioning; improved Geri-chairs
- Functional furniture
- Adapted clothing, eating utensils, and self-care devices
- Environmental controls
- Low-vision aids, audio books, better lighting
- Communication devices; longer-life batteries for hearing aids
- Balance aids; fall warning devices
- Memory aids

This list is by no means exhaustive, but it includes many devices commonly used for other disabilities. Rarely are they seen, or even suggested, in the nursing home setting. Experience with technological solutions for the institutionalized elderly has demonstrated profoundly successful outcomes, significantly improving the quality of life of the nursing home resident. Many improve functional independence enough to return to the community.

## Summary

As a society, we are confronted with increasing numbers of older Americans, many of whom are institutionalized in nursing homes due to significant losses in functional ability. Technology has developed rapidly, and technological interventions in restoring or aiding independent functioning have become standard in the rehabilitation of persons with disabilities. Unfortunately, these principles are not being applied for those elderly in nursing homes who would benefit from such applications. As technology increases, so too must education to policymakers, service providers, researchers, care-givers, case managers, third-party payors, and to the elderly themselves. Established rehabilitation interventions are applicable to all with difficulty in performing tasks (disability); this should not exclude the application of assistive technology to those who seek care in nursing homes.

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Carol A. Sheredos, P.T., Director
Meridian Rehabilitation Services
Meridian Healthcare, Inc.
515 Fairmount Avenue
Towson, MD 21204

5.3

# A VIDEO OBSERVATIONAL DETECTION SYSTEM TO CAPTURE FALL AND NEAR FALL INCIDENTS AMONG ELDERLY NURSING HOME RESIDENTS

Roger D. Bodenheimer, Bettye Rose Connell, Steve H. Fazenbaker, Eliece G. Gifford
Rehabilitation Research and Development Center, VA Medical Center-Atlanta

ABSTRACT

A video tape observational methodology and modified ultrasonic intrusion alarm system were developed to study the role of environmental and behavioral factors in naturally-occurring falls and near falls among elderly nursing home residents. Environmental and behavioral factors constitute the situation in which falls occur and are not well studied. We are utilizing falls incidents which would occur whether or not the study was being conducted, no falls are being induced. The use of video technology and observational methodology allow a comparison of the relative accuracy of primary data on fall events (video records) with post-incident self report data (fallers' verbal reconstructions) and secondary data (falls incident reports).

BACKGROUND

The observational detection system was developed to collect primary data in the Merit Review funded research project titled "Environmental and Behavioral Factors Among The Elderly." The problem of falls among older people is the major focus of the study. Previous falls research has focused on the faller rather than the situations or circumstances in which falls occur. This has resulted in a limited understanding of the various causes of older people's falls. In addition, previous falls research has been characterized by the use of self-reported reconstructions and secondary data sources such as nursing home falls incident reports.

The observational detection system uses modified ultrasonic intrusion alarms, charged couple device (CCD) cameras, surveillance video casette recorders (VCRs), and an infrared lighting system. Integrating video and ultrasonic intrusion alarms produced a system that could detect and document naturally occurring fall and near-fall events among the institutionalized older participants. Participants in this study were residents of the Atlanta VA Medical Center Nursing Home Care Unit. All were volunteers, and all exhibited normal cognitive abilities, ambulated without wheelchairs, and have a history of falling.

RESEARCH QUESTIONS

Some of the key research questions that need to be examined concerning falls are:

1. Do visual and acoustic distractions divert attention from mobility and balance-maintaining activities (standing up, walking) and/or objects and environmental conditions which are potential trip and slip hazards (chair leg, damp floor)? Are the distractions associated with potentially hazardous body movements such as rapid head rotation? Do such distractions distinguish fall and near fall events from nonfall events?

2. What activities are associated with falls? Are there differences in the activity sequences which precede falls and near falls, and those which precede nonfall events? What are the apparent interactions of these activity sequences and architectural / environmental conditions?

3. What are the roles of architectural factors and ambient conditions, such as spatial design, flooring materials and glare, in fall and near fall events?

4. Do the actions of those helping the older people to stand, walk, rise from a chair, etc. (trained staff, untrained friends and relatives) contribute to fall and near fall events?

5. Are primary falls data (video data) more complete and more accurate than self-report (fallers' verbal reconstructions) and secondary falls data (fall incident reports)?

Also, few studies have examined the broader social context in which falls occur. For example, what other people were present, what were they doing, and could they have helped prevent the fall if they had proper training.

The observational detection system was developed to facilitate the investigation of falls and their prevention.

## METHOD

A system composed of two strategically placed CCD cameras, a modified ultrasonic intrusion alarm, and infrared lighting components was installed in each participant's room. The system continuously monitored and recorded the participants' movements in their room. Thus it was able to capture fall and near-fall events for later analysis. The study did not have to rely on artificially induced falls or post hoc data.

Video cameras were mounted in the ceiling and positioned to capture all movement in a participant's room. The field of view included both sides of the bed and all available floor space. No recording was done in the bathroom areas in order to protect the participants' privacy. Since the CCD camera has the capability of picking up infrared light, the infrared lighting system installed in each room permitted recording at night. Cables linked each camera to a central location in the nursing home which contained surveillance VCRs and a monitoring system for camera viewing.

The ultrasonic intrusion alarm consists of a transmitter and receiver of ultrasonic waves. The transmitter projects a cone-shaped pattern of ultrasonic sound, and the receiver "listens" for echoes produced by a person's movement in the room. When the receiver detects movement in the cone-shaped pattern of ultrasonic sound, it activates an alarm (contact closure switch) at the alarm input terminal of the surveillance VCR. The surveillance VCRs are set-up in the time lapse mode where the pictures are recorded on a field-by-field basis (facilitating long periods of recording). Once the VCR alarm input terminal detects an alarm, the VCR switches from time lapse mode into real time recording mode. The VCR continues to record as long as the ultrasonic intrusion alarm in the participant's room detects motion.

When the ultrasonic intrusion alarm unit no longer detects movement, the surveillance VCR concludes the real time recording after an additional thirty seconds. Thus it returns to the time lapse mode of operation. This feature limits the length of tape to be reviewed in the analysis part of the study.

## DISCUSSION

The video recording surveillance system described in this paper allows behavioral researchers to identify and classify naturally occurring fall and near-fall incidents among older nursing home residents. The system permits unobtrusive observation and recording of these fall, near-fall and non-fall events as they occur. Thus it provides a research basis for the development and evaluation of interventions addressing environmental and behavioral contributions to falls in the older population. The types of interventions which might prove effective include: building design guidelines; facility maintenance procedures; training programs to reduce hazardous behaviors, and proper staff training. The long-term objective of this study is to use the research to design and evaluate interventions which help reduce the occurrence of falls among the elderly.

## ACKNOWLEDGEMENTS

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Roger D. Bodenheimer
VA Medical Center
Rehabilitation Research & Development Center (153)
1670 Clairmont Road
Decatur, Georgia 30033

5.4

# Design Features of Medication Organizers and Dispensers: Evaluation by Older Adults

Paula Guerette & Richard Nakai
Research & Training Center on Aging
Rancho Los Amigos Medical Center
Downey, California

## ABSTRACT

Due to common physical and psychological changes which can occur with age, many older adults experience "polypharmacy," the concomitant use of multiple medications. Motivational, cognitive, and sensory-motor factors all contribute to a lack of consistency in medication-taking in this population. To improve consistency, various methods have been investigated including a reduction in the complexity of drug regimens, patient education regarding illness, importance of drug therapy, side effects of drug therapy, and the use of physical aids. Although physical aids have contributed to more consistent medication-taking, it is often difficult to determine which aids are appropriate for older populations since there are many different products on the market. As such, there is an apparent need to examine and compare these products to determine appropriate design features for older adults, especially those with functional limitations. If products are designed with more capabilities of older adults in mind, this may lead to greater ease of use, reliability and acceptance of physical aids, and thus, may lead to greater consistency in medication-taking.

## BACKGROUND

As individuals age, they tend to become more vulnerable to illness and disease, and thus, experience the difficult situation of "polypharmacy." In fact, in a study of 244 individuals over the age of 60 years, (cited in Nambudiri & Shamoian, 1986), Chien et al. found that 83% of individuals were taking two or more medications. Since many medications require multiple doses per day, this can result in a complicated medication regimen.

Consistency in medication-taking has become a major health problem, especially among older adults. Research indicates that noncompliance rates can be as high as 93%, with an average rate of 40% (Eraker, Kirscht & Becker, 1984; Greenberg, 1984; Sackett, Haynes, & Tugwell, 1985). Numerous research studies have directly associated medication noncompliance with poorer treatment outcomes for such conditions as diabetes, epilepsy, hypertension, and some infectious diseases (e.g., Abdi & Gustafsson, 1989; Inui, Yourtee & Williamson, 1976).

Medication noncompliance can occur in numerous ways. The most frequent types of noncompliance are medication overdosage, either from taking greater than prescribed doses or taking the same drug from more than one bottle, and medication omission. Overmedication can exacerbate the potential side effects of the medication or cause severe interactions with other medications, while undermedication may increase the severity of the disease and lead to hospitalization or rehospitalization. Less common errors in medication-taking, albeit no less important, include taking drugs in the wrong sequence or in the wrong order, taking discontinued medications, taking medications without following the warnings on the label, and taking another individual's medications.

Numerous factors can affect consistency in medication-taking. An individual's motivation to maintain a medication regimen, as well as his or her cognitive, sensory, and motor capabilities all affect consistency of medication-taking. Physical aids such as pill containers, drug identification cards, and unit dose packing have been used successfully as a partial solution to improve consistency in medication-taking (Rudd, 1979; Sau Mei Wong & Norman, 1987). However, many of these devices have not been developed with geriatric individuals in mind. Some are difficult to open, others have extremely small spaces in which to place pills, while others use lettering that may be extremely difficult to see. It is anticipated that use of specific design considerations could make medication dispensing and organizing products more acceptable, more reliable, and easier to use by older adults. Better designed physical aids could assist older adults in improving consistency of medication-taking, especially if an overall strategy of medication-taking encorporates other solutions such as patient education or simplification of medication regimens.

## STATEMENT OF THE PROBLEM

Many medication organizing or dispensing products have been designed without knowledge of the most appropriate design features for older adults. While they may be useful for some individuals, many older adults cannot receive the full benefit of these devices as they are currently designed. To improve ease of use and perhaps improve consistency of medication-taking, medication dispensing and organizing devices need to address the sensory, motor, and memory limitations that face many older adults today.

## APPROACH

Criteria related to medication dispensing and organizing devices which are particularly relevant to older adults have been identified. An initial list of product criteria was established by interviewing professionals in the fields of gerontology, pharmacology, and technology. This list was refined based on feedback from a focus group held with older adults. These individuals identified the criteria believed to be important with regard to medication organizing and dispensing products, and rated each criterion in terms of its degree of overall importance. Among the factors rated as important were ease of opening/closing, space on product for labeling medications, ease of instructions, cost, and reliability.

A review of product databases, as well as product catalogs, was performed to determine the products available to consumers. It was found that this product domain includes medication organizing and dispensing products which vary along a continuum of complexity, from very "low tech" pill organizers of different kinds, shapes, and colors, to very "high tech" devices which can be programmed to dispense medications automatically. From this, a representative range of products to be evaluated was established.

Samples of nine different products which span the complexity continuum have been obtained for evaluation. At the lower end of complexity, three products which simply hold and/or sort medications will be evaluated. These products differ, among other things, in size, color coding, number of different pills which can be accommodated, method of opening/closing, and labeling. Slightly more complex are the products which act as timers and can be set to provide an auditory signal at specified intervals in time. These products have a visual display, similar to that of a small alarm clock or calculator, and must be reset each time they ring. Areas in which these products differ include size, number of pills accommodated, method of setting alarms, and height of numbers on display. Finally, at the high end of complexity are three products which can be programmed to sound a signal for several doses per day for multiple medications. These products differ in terms of programming requirements, method of dispensing pills, ability to track and record pills missed, size/portability, and size of visual display, as well as in additional features such as printed reports and warnings provided.

In order to establish the product features which are appropriate for older adults with functional limitations, the products will be evaluated by older adults with sensory, motor, and memory limitations, as well as by their caregivers. Products will be tested in the laboratory to determine initial comprehensibility of instructions and initial ease of use in terms of opening, closing, loading pills, dispensing, etc. Each product will then be used in the home to establish impressions of the product design features over an extended period of time, as well as to determine whether the use of these products can improve consistency of medication-taking.

## IMPLICATIONS AND DISCUSSION

It is anticipated that product features designed specifically to address the functional capabilities of older adults may enhance the utility and acceptance of these products. If medication dispensing and organizing devices can be used easily and reliably by older adults, these devices could improve consistency of medication-taking, especially if used in conjunction with other strategies.

From the objective and subjective data acquired during the evaluation process, information will be obtained regarding the appropriateness for older adults of various design features such as size/color of print, method of opening/closing, method of loading/dispensing, ease of reading/following directions, etc. Feedback will be provided to manufacturers regarding both the appropriateness of their existing product features, and potential modifications which could be implemented to improve product use by older adults. In addition, product summaries will be provided to consumers to help them select products appropriate for individuals with various functional limitations.

ACKNOWLEDGEMENTS

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Paula J. Guerette, Ph.D.
Harriman House
7600 Consuelo Avenue
Rancho Los Amigos Medical Center
Downey, California 90242

# BALANCE DIAGNOSIS USING A WEARABLE UPPER BODY MOTION ANALYSIS COMPUTER

5.5

Eric E. Sabelman, James J. Gadd, Deborah E. Kenney, Paul M. Merritt, Carol H. Winograd †
Palo Alto VA Medical Center, Rehabilitation R&D Center, and
† Geriatrics Research, Education and Clinical Center

## ABSTRACT

In a previous report [1] we described a pilot study on upper body accelerometry to measure aging-related changes in balance, with the ultimate aim of preventing falls or minimizing resultant injury. Pilot data were obtained using a set of head- and waist-mounted accelerometers tethered to a stationary computer by cables. This paper reports on a new wearable computer-based data acquisition system that permits unconstrained motion. Data were compared to postural stability derived from a self-administered questionnaire, a physical examination and evaluation of videotapes of subjects performing standard balance-assessment tasks.

## BACKGROUND

Postural stability declines with age due to combined vestibular, proprioceptive and visual losses, resulting in impaired mobility and increased risk of injurious falls [2]. The ultimate goal of this project is to develop a wearable accelerometric instrument -- a "balance orthosis" -- making it possible to record an individual's movements during everyday activities in a non-laboratory setting, identify patterns of movement that accompany loss of balance before a fall actually occurs, alert the individual of pre-fall behavior, and if necessary, signal a remote attendant that a fall has taken place. In the short term, we expect the instrument to be useful for quantification of hitherto qualitative clinical diagnosis of balance disorders.

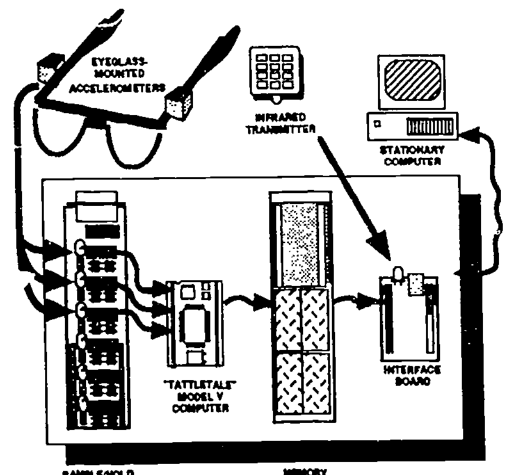
One major objective is to create a means for real-time quantitative body motion analysis outside the laboratory, in the same environment and situations in which people actually fall and injure themselves. Quantitative balance assessment presently can be done by video image analysis [3] or by moveable force platforms [4]. However, these require that the patient be brought to the laboratory; they cannot duplicate all the factors which may lead to a fall, and they are expensive ($100,000 to $200,000, or $360 per use). One force platform, the "Equitest" permits controlled induction of falls and separation of vestibular from visual feedback [4]. On-site balance assessment is usually performed by a trained physical or occupational therapist, and consists of qualitative "steady/unsteady" judgements during observation of the subject performing a series of standardized motions [5]. Our instrumentation will allow these subjective measures to be quantified and compared to normal motion signatures stored in computer memory.

## METHODS

The wearable balance assessment system employs twelve ±5 g range monolithic silicon accelerometers in surface mount packages, which are small enough for unobtrusive mounting on the body, even after assembly of three devices for multi-axis sensing. A 3-axis assembly is mounted on each corner of an eyeglass frame to measure head motion and also on the left and right sides of a Velcro-covered waist belt to measure trunk accelerations. Also on the belt are the data recording computer and a battery pack. Cables from the sensors go to sample-and-hold amplifier boards inside the wearable computer/recorder, thus allowing the wearer to move about without being tethered to a fixed computer.

The off-the-shelf single-board CMOS computer ("Tattletale Mark V", Onset Computer Corp, N. Falmouth, MA) digitizes the 12 amplifier outputs at 1 part in 1024 accuracy (10 bits) at 20 to 100 millisecond intervals. Also in the 6.5 X 2 X 3 inch package are an interface board and a 2 megabyte memory board [Figure 1]. After 40 to 180 minutes of data collection, a telephone-type modular cable is plugged into the interface board to send the stored data to a fixed computer for processing. Recording is started, stopped and coded for identification of the wearer's activity using an infrared remote control, so the experimenter does not have to physically contact the device while recording.

FIGURE 1: ACCELEROMETRIC BALANCE DIAGNOSIS SYSTEM (waist sensors omitted)




A medical history for each subject is obtained via a self-administered questionnaire and a physical examination. These and the qualitative assessment protocol for comparison with the accelerometric score include all non-duplicated items from four published balance and activities of daily living (ADL) assessment methods (Tinetti [5], Wolfson [6], Reuben & Siu [7], and Lemsky [8], *et al.*).

During a test session the subject wears the accelerometer-equipped eyeglass frames and waist belt. To document displacement directly, reflective tape markers are attached to legs, trunk, arms and head; these are videotaped for later image analysis and qualitative balance assessment using orthogonal split screen recording [Figure 2]. The subject's segmental dimensions and locations of reflectors are measured for use in calculating angular acceleration and velocity.

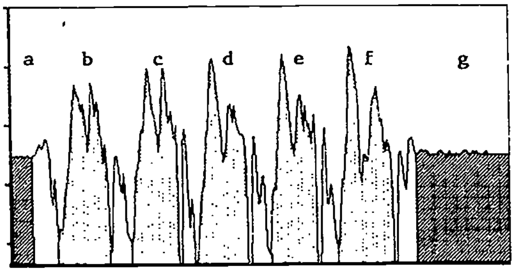
FIGURE 2: SPLIT-FRAME VIDEO OF TEST

Subjects then performed 65 tasks, in the following categories:

- motionless standing and sitting (to calibrate initial and post-test angles of accelerometers)
- standing: eyes open, eyes closed, on toes, on soft foam, toe-to-heel (tandem stance), on one leg
- simple motions: turning and tilting head and trunk, reaching to left and right
- ascend 3 steps, turn, then descend 3 steps,
- rise from and sit in a chair,
- pick up and replace objects (penny, 1 kg weight) on floor, overhead, on a shelf
- walking: natural pace, tandem, step over 2, 4 and 8-inch obstacles.
- ADL: talking, simulated eating, writing, putting on a coat, opening a door

The first step in quantitative post-test data analysis is to define the start and end of the activity. The raw data contains baselines at the beginning and end of an activity due to having the subject motionless before and after the activity. The mean and standard deviation (SD) of the first ten data points are calculated. Data are then compared to this mean point-by-point until one point is found to be 2 SDs from the mean. This point is then considered to be the beginning of the activity [*a* in Figure 3]. The end of the activity is found in the same manner by starting at the end of the data file and moving backwards through the data [*g* in Figure 3]. Where the activity is repeated, the maxima, minima and/or slope of single sensors are determined and used to define beginning and ending of a single activity [*b, c, d, e, f* in Figure 3].

FIGURE 3: PARTITIONING OF DATA FILE (illustrated: 5 repetitions sit/stand)




## RESULTS

Twelve elderly (5 male, 7 female, ages 63 to 81 years) and 5 young (21 to 34) subjects were examined. All were mobile and independent with respect to ADLs. Performance on qualitative assessment was nominal except for the seven tasks shown in Table 1, with the most failures in eyes-closed tandem standing and standing on one's toes for 15 seconds each.

TABLE 1: QUALITATIVE INSTABILITY

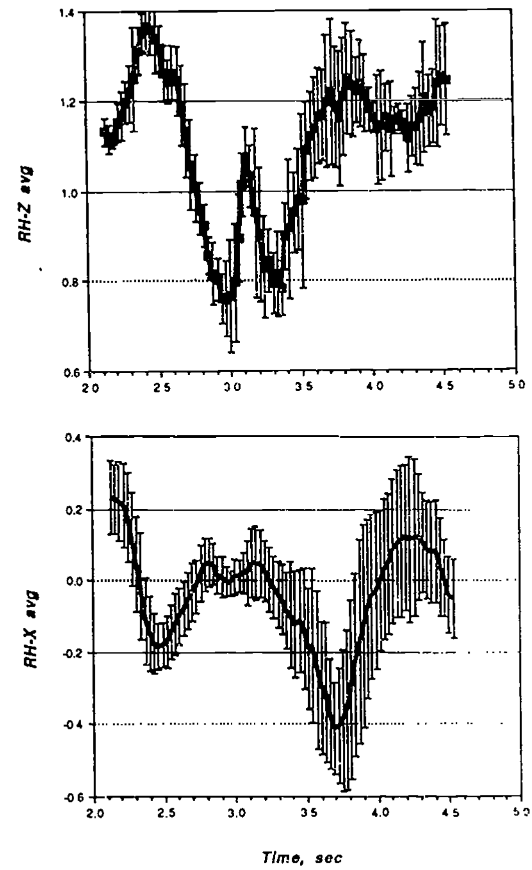
| | ALL ELDERLY (N=12) | FEMALE (N=7) | MALE (N=5) |
|---|---|---|---|
| LATERAL REACH | 25% | 43% | 0% |
| UPWARD REACH | 42% | 43% | 40% |
| STAND ON TOES | 67% | 86% | 40% |
| 1 FOOT STANCE | 33% | 43% | 20% |
| TANDEM STANCE | 58% | 43% | 80% |
| TANDEM WALK | 42% | 57% | 20% |
| BARRIERS | 25% | 43% | 0% |

Figure 4 is an example of derivation of a subject-specific motion signature for a single task, in this case sitting and rising from a chair, repeated 5 times in rapid succession. The anterior/posterior horizontal (Z-axis) signals at the right head were converted to gravity units (g = 9.8 m/sec) and processed as shown in Figure 3. The mean and SD of the 5 repetitions were calculated after matching the minima and preceding slope of the right head Z-axis sensor. Figure 4 shows the 40 points (1.2 sec) before and after the matched point on the Z-axis at the head. Angle of inclination in the sagittal plane can be found by vector addition of the X- and Z-axes.

## DISCUSSION

In the present series of tests, active elderly, without a history of falling, had the greatest difficulty with tasks that required decreased base of support (*e.g.*: standing on toes, tandem walk/stance). Half of female elderly also had problems walking over barriers and lateral reaching. Accelerometric data on the same tasks corroborated these findings. Accelerometry is most sensitive to the start and end of volitional motion, tremor and uncontrolled oscillation, impacts such as heel strike while walking, and abrupt tilting of the head or trunk, as upon losing one's balance.

FIGURE 4: MEAN & STANDARD DEVIATION OF 5 REPETITIONS SIT-TO-STAND/STAND-TO-SIT, Z & X axes (young subject: DK)




We are continuing to derive "normal" (uniform regardless of age) and age-modified acceleration signatures for all the balance assessment tasks according to the model of Figure 4. In this example, since variation in duration of each of the 5 trials was not matched, the SD tends to increase with time after the matched point; multipoint matching with interpolation assuming a constant interval between points would correct for this variance.

The number and distribution between male and female subject of failures to perform qualitative balance tasks is ascribable at least partly to lower limb muscle weakness [9]. Reaching, standing on tiptoe and on one leg all require high muscle forces more easily generated by men than women. Tandem stance and gait place greater demands on small muscles of the foot; however, the cause of the 80% failure rate among males is not known. The stepping-over-obstacles test was newly devised to simulate real-world curbs and thresholds; it appears to be more difficult for women than for men.

While the activity series which subjects are asked to perform is relatively complete, other tasks which might be added include simulation of uneven surfaces such as gravel and ridges under carpet, standing with the legs crossed (an extreme form of tandem stance), standing on a beam with toes and heels unsupported [Horak, personal communication], carrying an asymmetric load, and placing an object on a low shelf [10].

There are other uses for body motion analysis under real-world conditions, such as in sports training and in occupational injury prevention and rehabilitation. For these purposes, accelerometric sensors might be attached to molded splints on the wrists, to shoes or to straps on the arms or legs for monitoring other body segments besides the head and trunk.

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6.1

# BIANGULAR BACK (BAB) - CONCEPT NOT COMPONENT
## *A Five Year Retrospective*


Mary Ellen Gorden, OTR — Rehabilitation Designs, Inc.
Simon A. Margolis, C.O. — Rehabilitation Technologists, Inc.



### ABSTRACT

The most difficult, and often perplexing, problems facing clinical seated positioning practitioners are pelvic alignment and stabilization, and head control/position. Over five years ago, we, along with many of our colleagues, adopted a substantially different conceptual approach to addressing these problems. The heart of the approach includes the use of the BiAngular Back design coupled with a major emphasis on the interrelationships among the positions and orientations of different parts of the body. This holistic approach is coupled with a continuing awareness of the functional needs of the client and their care givers. This formula has led to great success in meeting the needs of many people who in the past have attained only marginal results from seating efforts.


### BACKGROUND

Determining the etiology of most head control and position problems requires looking past the obvious. The position of the pelvis and the presence, or lack, of natural complimentary curves of the spine is virtually always a major contributor to head control/position problems.

Though balancing the head over the pelvis by repositioning the spine with a more natural lumbar lordosis, thoracic kyphosis, and cervical lordosis does not in itself assure appropriate head position; an unnatural alignment of the spine, both anteriorly/posteriorly or medially/laterally, almost always causes head control/position difficulties.

When the concept of the BAB was first discussed in 1987[1] there were a great many practitioners unaware of, or ignoring, basic bio-mechanical considerations. The commonly accepted approach to dealing with the problems of "thrusting hips" i.e., increased, often uncontrolled, activity of primarily the hip extensor muscles, was to decrease the seat to back angle of the seated positioning system with hardware, by using a rolled or wedged seat, or by the unfortunate misuse of a valuable positioning tool; the anti-thrust seat.

This approach was (and still is) used repeatedly without taking into consideration:

- limitations to true acetabular hip joint range of motion

- the effectiveness of the anterior seating components to maintain the requisite pelvic position

- the relationship of the angle of the anatomical hip joint to the mechanical seat to back angle of the seating system[2]

Though a great number of people are now more aware of these and other limiting factors in using a ninety degree, or less than ninety degree, seat to back angle; the use of seating system designs that address these basic biomechanical issues has only recently increased.

Almost all of the commercially available seated positioning system are provided with a basic seat to back angle of 90 degrees. Though custom designs are often available from these manufacturers; the indications for their use are not well publicized nor documented.

### INDICATIONS

Since the design of the BiAngular Back promotes the natural alignment of the spine, we suggest that it's use is almost universally indicated. In our clinical practices, the Bi-Angular Back is used for virtually all our clients who require linear seating systems, subject to the contraindications listed below. The concept of the BAB can easily be applied to direct molded systems, eg., Foam-in-Place, Bead Seat, etc., as well as to indirect molded systems such as Contour U or Summit.

We hope that you and your colleagues will think of other contraindications as well. We urge you to share them with us.

Generally, the BAB is contraindicated:

- *When the referring clinician or rehabilitation technology supplier does not fully understand the concept, the application, the design or the implications of using an aggressive, holistic approach to seated positioning.*

One of the barriers to the acceptance of the BAB has been the fact that the concept has been widely misunderstood and misused by often well intentioned, though poorly prepared or informed, individuals.

- When the client and/or primary care givers are extremely resistant to change and "new ideas".

- When the client wears a Thoraco-Lumbo-Sacral Orthosis (TLSO) or other type of external spinal support when seated in the positioning system.

- When the client has undergone a spinal fusion or has developed bony changes in the spine. These situations, as well as the use of a TLSO, fix the amount of lumbar extension available, thus negating the effectiveness of the BAB concept.

- When there are respiratory, circulatory or other systemic contraindications to the pelvis being anteriorly tilted and the lumbar spine extended.

Other than these situations, we feel that the BAB concept, to a greater or lesser extent, will benefit almost all clients. The magnitude of the benefits gained must be weighed against the additional cost and effort of the BAB design.

Generally, the BAB is no more difficult, and only nominally more expensive, than many other more standard back designs. When using the BAB concept with a molded system, there is virtually no additional cost nor effort involved.

## CONCLUSIONS

This paper is not intended to present all the permutations and ramifications of the Bi-Angular Back design as it relates to positioning people with disabilities. The concept has, however, become a valuable tool for at least 75 seating practitioners around the United States and Canada. We conservatively estimate that over 3000 clients are using seated positioning systems incorporating the BAB design.

*We strongly recommend that you get further information and instruction before implementing these ideas.*

Once understood and mastered, use of the BAB concept will improve the seated position, head control and upper extremity function of many of your clients.

Mary Ellen Gorden
Rehabilitation Designs, Inc.
901 Watson Avenue, Suite 102
Madison, WI 53713
1-800-783-1734

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6.2

# Integrating Control of Multiple Assistive Devices: When is it Appropriate?

Paula Guerette, Kevin Caves, Richard Nakai & Eunice Sumi
Rehabilitation Engineering Center on Technology for Children
Rancho Los Amigos Medical Center
Downey, California

## ABSTRACT

Technological advances now allow control of multiple assistive devices to be integrated to a single input device. However, little information is available to help therapists determine when integrated controls should be recommended. A retrospective study of clients at the Center for Applied Rehabilitation Technology was performed to determine factors which suggest when integrated controls are and are not appropriate. Integrated controls appear to be appropriate when: 1) the "best" method for controlling each assistive device is the same; 2) the individual has a single, reliable access site; and 3) the individual prefers integrated controls for subjective reasons. However, there are several reasons why integrated control is not always warranted. First, integrating control often results in performance trade-offs. Second, the cognitive demands of integrated controllers are greater than those involved in using dedicated controls for each device. Third, technical limitations may restrict the use of integrated controllers with some equipment. Finally, if funding is restricted, the added cost (up to $3500) may not be justified.

## BACKGROUND

Previously, individuals who used more than one assistive device were required to control each device separately. In these cases control was "distributed" to multiple input devices such as switches and joysticks, and often to more than one access site. Using distributed controls was often difficult for individuals with limited reliable access sites. In addition, multiple input devices could make a system more cumbersome to use, and less visually pleasing.

In the past decade, systems have been developed for specific individuals which combine control of multiple assistive devices to a single input device. For example, Braswell & Buckett (1983) designed several configurations of combined wheelchair and recliner control for shoulder control wheelchair users. One of these systems allocated recliner control to the same shoulder switch used to control the wheelchair. The "Lainey" System (Romich, 1984; Trefler, Romich & Russell, 1985) and the "Tamara" System (Bresler, 1989) combined control of powered mobility, communication, and environmental control all to a single input device. The Lainey system also provided control of a computer through this input device. The development of these systems with "integrated" controls demonstrated that a microprocessor-based system could be used to integrate control of multiple assistive devices.

Although the systems presented above were developed for specific individuals, integrated controllers have recently become available on a commercial basis. These integrated controllers offer therapists greater flexibility in making recommendations to clients. For example, the same joystick or switches which are used to control a wheelchair can now also be used to control a communication device, a computer, a recliner, and an environmental control unit. However, this technology is relatively new and as such, there is little information to suggest when the use of integrated controls is appropriate.

To determine when integrated controls are appropriate, two concurrent projects are being conducted. The first of these involves a retrospective review of all patient charts at the Center for Applied Rehabilitation Technology (CART) to determine the factors involved in the recommendation of integrated controls. The second is a performance study which examines how well disabled individuals are able to access various assistive devices using both integrated and distributed controls. The results of the retrospective study are addressed in this paper.

## RESEARCH QUESTION

Integration may be clinically advantageous in some cases. However, it is also possible that integrated controls may actually interfere with a user's performance. The current project seeks to determine the factors which support integrating control of multiple assistive devices and those which suggest that control be distributed across multiple input devices. From this information, guidelines for therapists will be established to assist with the recommendation of integrated controls.

## METHOD

Since the major commercially available integrated controllers operate through the wheelchair input device, only those individuals receiving a recommendation for powered mobility were entered into the retrospective study. For each individual entered in the study, information was obtained regarding the specific disability, available access sites, appropriate access methods, and system configuration recommended by CART therapists. Through a review of the patient data collected, as well as through consultation with CART therapists, reasons for recommending or not recommending an integrated system were determined for each individual.

## RESULTS

A total of 170 charts were reviewed. Of these, 117 individuals were excluded from the retrospective study, either because they were not powered mobility users or because they did not receive an equipment recommendation from CART.

Forty-four of the remaining 52 individuals (85%) received recommendations for systems with distributed controls. The primary reasons cited for not prescribing integrated controls to these 44 individuals included speed, accuracy, and ease of use of distributed controls, as well as cognitive limitations which precluded the use of integrated controls. For nine of these individuals, therapists reported that integrated controls would have been a clinically feasible recommendation. However, integrated controls were not recommended in these cases due primarily to personal preference of the user and additional cost of the integrated controller.

In 41 of the 44 cases where distributed controls were recommended, it would have been technically possible to integrate the control of additional assistive devices through the wheelchair input device, assuming the individuals were provided with the proper wheelchair electronics. For the remaining three individuals, their prescribed assistive devices could not be integrated through any available integrated wheelchair controller.

Of the nine who were recommended integrated controls, one was not able to use distributed controls due to physical limitations. This individual had a single reliable access site. Therefore, integrating control allowed access of multiple assistive devices through a single input device. For two others, the best mode of access for each assistive device, when evaluated independently, was found to be the same. Thus, these individuals benefited from the use of integrated controls.

The remaining six individuals were physically able to use systems with distributed controls. However, four of the six performed better with integrated controls and found them easier to use. All reported a personal preference for integrated controls -- one reported that integrated control minimized the number of access devices required and provided a "neater" looking system. Interestingly, one of the six actually accessed a communication device more slowly with the integrated system but preferred it for a number of subjective reasons, including aesthetics.

## DISCUSSION

Although these findings will be enhanced by data from the performance study, an initial review of the retrospective data indicates that several factors are important in the recommendation of integrated controls. First, integrated controls appear to be appropriate for clients whose "best" method for controlling each individual assistive device is the same. Integrated controls are also appropriate for those who have only a single, reliable access site. Finally, integrated controls are appropriate for subjective reasons, including aesthetics and perceived performance.

Despite reasons for recommending integrated control, it is not appropriate in many cases. Integration often results in performance trade-offs, especially if an individual must use a less appropriate mode of access for one or more assistive devices in order to integrate control. The cognitive demands of integrated controllers appear to be greater than those involved in using dedicated controls for each device. It is not always technically possible to integrate all equipment. Finally, if funds are restricted, the added cost of up to $3500 may not be justified.

## ACKNOWLEDGEMENTS

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Paula J. Guerette, PhD
CART
7601 East Imperial Highway
Rancho Los Amigos Medical Center
Downey, California 90242

# DYNAMIC TESTING OF CUSTOM SEATING SYSTEMS FOR TRANSPORTING CHILDREN WITH PHYSICAL DISABILITIES IN MOTOR VEHICLES

Steve Ryan, Margaret Young, Dianna Fong, and Stephen Naumann
The Hugh MacMillan Rehabilitation Centre,
Toronto, Ontario, CANADA

## ABSTRACT

Published studies have indicated that unmodified custom seating inserts for children with disabilities are not designed to withstand the forces that can be generated during a motor vehicle accident.

As part of a project to develop a system for upgrading custom seating inserts so that they can be used in motor vehicles, three different impact tests were conducted to investigate both the dynamic performance of a typical custom seating insert and the response of a child-size anthropomorphic dummy.

The results of the impact tests demonstrated that an insert that has been provided with an appropriate support frame and belting arrangement can provide children with physical disabilities the same level of protection as their able-bodied peers. It was found that this can be accommodated without compromising the therapeutic support required.

## BACKGROUND

Being properly restrained in a motor vehicle presents special problems for many children with physical disabilities. Commonly, they require specialized postural seating support and are often unable to use standard, commercial types of car passenger restraints alone because of dependent sitting, skeletal deformities and/or uncontrolled head movements (1,2).

Faced with having to transport their children, parents and caregivers often have no alternative but to position their children in postural support devices and secure them using the vehicle lap belt and the straps provided with the seating systems. An even less desirable situation positions the child on another passenger's lap with a single seat belt around both.

While the disabled child may be adequately supported during normal automobile manoeuvres, such arrangements violate basic crashworthiness principles and could contribute to, rather than prevent, serious occupant injury or death during an automobile accident (3).

Recognizing the unique positioning requirements of physically disabled passengers, Transport Canada recently issued Canadian Motor Vehicle Safety Standard (CMVSS) 213.3 - Restraint Systems for Disabled Persons. In CMVSS 213.3, a production seating systems used for transportation must meet specific performance criteria for certification.

## METHOD

Dynamic tests

The goal of the test programme was to examine the impact performance of various restraint arrangements and to compare the performance with relevant dynamic requirements of federal regulations for child restraint systems.

To comply with the regulations, the maximum forward head excursion for the test dummies must not exceed 720 mm (28.5 inches) from a reference point on the impact sled. Also, the chest acceleration of the instrumented dummy must not exceed a loading of 60 g's for more than 3 milliseconds.

Dynamic tests were conducted at the Impact Studies Facility of the Defence and Civil Institute of Environmental Medicine (DCIEM) in Downsview, Ontario. At DCIEM, a crash-simulator system is used to provide impacts which are typical of vehicular crashes. The simulator is intended to mimic the response of a head-on vehicular collision of 30 miles per hour into a stationary object (as required by CMVSS 213.3).

Three impact tests were conducted. In each case, an instrumented anthropomorphic dummy was used to simulate a three year-old child. An identical custom foam-and-plywood insert was provided for each test, however, the method of restraining the insert and securing the dummy was varied for each run.

Test run 1. To obtain baseline information, the first test involved using an unmodified, custom foam-and-plywood insert. Both the dummy and insert were restrained by the car lap belt to typify the arrangement used by most parents.

Test run 2. The second test used the same seat configuration, but it was upgraded to meet the requirements of CMVSS 213.3. Enhancements included using upper and lower torso restraint belts,

and a suitably anchored tether strap to limit rotation of the back support.
The vehicle lap belt was placed behind the dummy, but in front of the seat's hinge, to ensure that insert loads were not applied to the occupant during the impact.

Test run 3. The final test incorporated a prototype restraint system that consisted of a steel "conversion" frame, adjustable restraint belts, and hardware which was attached to the insert.

The conversion frame was designed to be the primary load bearing structure responsible for "riding down" car deceleration during a collision. It provided the anchor points for the occupant shoulder harness, pelvic belt, crotch belt, and tether strap.

The frame was an arrangement of tubular steel configured to rest on the car passenger seat and readily accept a custom seating insert removed from a wheeled mobility base.

## RESULTS

Quantitative results of the impact tests are provided in Table 1.

Test run 1. Results of the first run indicated that while chest accelerations were measured to be within the required level of acceptance, severe "jack-knifing" of the insert and dummy resulted in a head excursion nearly eight inches beyond the safe limit. These findings corroborate the results of earlier tests conducted by Transport Canada (4).

Chest acceleration was found to be within the bounds specified in CMVSS 213.3 for this test, however, the chest strap did not play a major role in restraining the dummy. The time and magnitude of maximum chest acceleration suggest that lap belt loading, although not measured, was likely very high.

Since the insert and dummy were both held using a single lap belt, the seat applied loading directly to the occupant during the impact. The vehicle lap belt was also found to be twisted following the test, suggesting that the load was not well distributed over the pelvis.

Test run 2. Results of the second test demonstrated marked improvements in the dynamic performance of the arrangement. Both chest acceleration and head excursion, remained below the limits specified in the standard.

While the plywood back of the insert sustained a severe, transverse failure across its width, the dynamic requirements of CMVSS 213.3 were marginally met. It was projected, however, that variations in seat height could result in values which exceed the limits set in the standard.

Test run 3. The final test conducted using the conversion frame showed head excursion and chest acceleration values that were also within the limits set in CMVSS 213.3.

The prototype conversion system demonstrated a dynamic performance which was consistent with the requirements for production child restraint systems. Controlled deformation of the frame assisted in reducing the severity of the impact.
Improvements were also observed in the measured response of the dummy and in the performance of the insert when compared to the other custom restraint arrangements tested.

## DISCUSSION

The modified seating arrangements tested were proven to upgrade custom seating inserts such that their dynamic performance matched that of production child car seats.

While the technical feasibility of upgrading inserts to meet federal standards was demonstrated by the results of run 2, the practical implications of proper belt management were of concern to clinical team members. They believed that the restraint belts would not necessarily provide proper therapeutic securement of the child. Hence, in addition to carrying these belts, the insert would also need to be outfitted with postural belts. As a consequence, it was believed that the extra belts would invite misuse of the securement hardware and would also likely create an arrangement which would be awkward for parents to use

These considerations and the results of the dynamic tests reinforced the need to provide a supplementary, detachable conversion system which would support the appropriate restraint belt arrangement, provide the necessary therapeutic support for the child, and be a functional system for parents to manage.

With the support of industry and seating clinics, a commercial version of the conversion system should offer many young children with physical disabilities the means for travelling safely in motor vehicles.

## ACKNOWLEDGEMENTS

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Steve Ryan,
The Hugh MacMillan Rehab Centre,
Rehabilitation Engineering Dept.,
350 Rumsey Road,
Toronto, Ontario,
M4G 1R8

| Run No. | Max.Head Excursion | Max Chest Acceleration | Time of Max. Chest Acceleration |
|---|---|---|---|
| 1 | 922mm (36.3") | 49 g | .102 s |
| 2 | 706mm (27.8") | 49 g | .063 s |
| 3 | 675mm (26.6") | 50 g | .056 s |

Table 1 - Values of head excursion, chest acceleration, and time of maxium chest acceleration from the onset of impact.

6.4

# Cold Weather Wheelchair Battery Performance

James J. Kauzlarich and Joanna Radford
UVa Rehabilitation Engineering Center
Charlottesville, VA 22906

**Abstract**

It is well known that batteries will deliver less energy under cold weather conditions, but this information is not usually available for wheelchair batteries. The capacity of two different types of deep cycle lead-acid batteries (wet cell and gel cell) used in electric wheelchairs was measured at room temperature and at freezing conditions.

The test results show that the wet cell is able to store more energy than the gel cell for the same size case under hot or cold conditions. Wet cell batteries cost about one half the amount of gel cell batteries, and are by far the most economical choice for wheelchairs. Until recently only gel cell batteries have been accepted for transport by some airlines, but under new DOT policy requirements (1990) airlines must accept all types of wheelchair batteries when properly stowed.

**Introduction**

In the United States there are more than 1,000,000 wheelchair users (Ref 1, p. 1), and it is estimated (2) that 25 to 30% of these wheelchairs (275,000) are powered. Since the market for wheelchair batteries is relatively small, the demand by wheelchair users for battery improvements goes unheeded by U.S. battery companies, whose economical interests lie primarily with automotive power sources (compare the need for about 500,000 wheelchair batteries per year with the usual production of 20,000 automobile batteries per day by one of the large battery companies). Because of this small market the test information on wheelchair batteries is lacking. In the case of cold weather conditions the performance data available from battery companies is for automotive starter requirements of 190 amps at 0 °F. The typical wheelchair draws about 7 amps average during operation, and cold weather test data is unavailable. Two common types of wheelchair batteries (wet cell and gel cell) were tested to generate performance data applicable to wheelchairs at room temperature and at freezing conditions, and the results are presented below.

**Method**

The important characteristic of the battery to the user is the time a battery will operate the wheelchair before becoming discharged, which is called the battery capacity in terms of ampere-hours; and this is generated by measuring the current and time for discharge of the battery. Since the capacity is mainly a function of type of battery, rate of discharge and temperature, these conditions were selected for testing.

Two common types of "deep cycle" batteries from Johnson Controls were tested. A 22NF wet cell battery of 60 ampere-hour capacity at 80 °F was tested. The 22NF represents the case size and the D represents "deep cycle." Deep cycle batteries are built of special materials resulting in a more rugged construction, which is necessary when a battery is often discharged deeply. Automotive batteries are designated Starting, Lighting and Ignition (SLI), and are normally not deeply discharged since the automotive charger keeps them fully charged. SLI batteries are constructed much lighter than deep cycle batteries. The wet cell is not maintenance free; it must be checked for electrolyte level and distilled water added as needed. The price of the wet cell batteries was $45 each. The other type of battery which was tested is the gel cell, which is nonspillable and maintenance free, and before 1991 was the only battery accepted by airlines. The gel cells tested were of the 22NF case size, designated GC12400 with GC12 representing "Gel Cell 12 volt," and the 400 meaning 40.0 ampere-hours capacity (80 °F) at the 20 hour rate of discharge of 2 amperes for this battery. The name gel cell derives from the fact that the electrolyte is gelled, but otherwise the battery is the same as a wet cell battery. Because the electrolyte is gelled there is a loss in capacity of 20 ampere-hours since the gelled electrolyte will not diffuse through the porous plates as easily as in a wet cell battery. The price of the gel cell batteries was $75 each.

Under room temperature conditions two 12 volt batteries connected in series (24 volts) were discharged to 12 volts, which is essentially the lowest voltage usable by a 24 volt wheelchair and represents a depth of discharge of 100%. An automatic cut off charger was used to recharge the batteries. Both a tapered current charger (Lestronic II) and an electronic charger (Invacare MC200) were used in the testing, each with automatic cut off. With the battery at room temperature there were no problems with the chargers.

The batteries were tested in a refrigerator with the freezer control set to produce freezing conditions (0 °C) surrounding the batteries. The charger was at room temperature and wired to the cold batteries. The automatic cut off chargers did not work correctly for gel cells, cutting off after a small recharge because the cold gel cell battery went through a dip in voltage during recharge that the charger interpreted as end of charge. By using a charger without automatic cut off it was possible to recharge the cold gel cell batteries without any trouble. We found the electronic charger was sensitive to line power surges, and would cut off when the refrigerator turned on.

**Results**

The results of the testing are presented in Figures 1 and 2. In both figures the fully charged battery was discharged at different values of constant current to 100% depth of discharge (DOD). The 100% DOD was assumed when the voltage of the two batteries in series fell to 12 volts. Although this is a constant direct current (DC) discharge, testing under pulse width modulated control which is used by electric wheelchairs gave similar results. We also tested the batteries under a variable load duty cycle, but found that the results did not differ significantly from DC conditions.

Both types of batteries gave the proper room temperature capacity at the standard 20 hour rate of discharge, as shown in the Figures. It is well known that above the 20 hour rate of discharge the capacity of the battery falls off, and this is shown by comparing the dashed line (constant energy) with the actual discharge line, with the difference designated "loss." For example, due to the loss in Figure 2, the battery will only operate for 1 hour at 20 amperes discharge whereas it should have operated for 2 hours. The "loss" is not as great for the wet cell battery (Figure 1).

Under cold conditions both batteries gave a lower capacity; 46 ampere-hours for the wet cell and 36 ampere-hours for the gel cell. The distance a wheelchair can travel is directly proportional to the ampere-hour capacity of the wheelchair. For example, in Ref. 3 we measured the performance of electric wheelchairs and found that a 24 volt wheelchair will do 0.19 miles/ampere-hour on an indoor track, and 0.42 miles/ampere-hour on an outdoor track.

**Figure 1: Wet Cell Capacity vs Temperature**

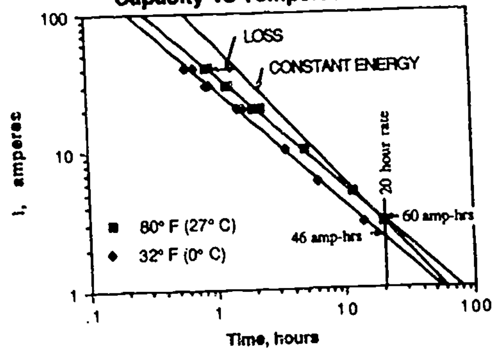
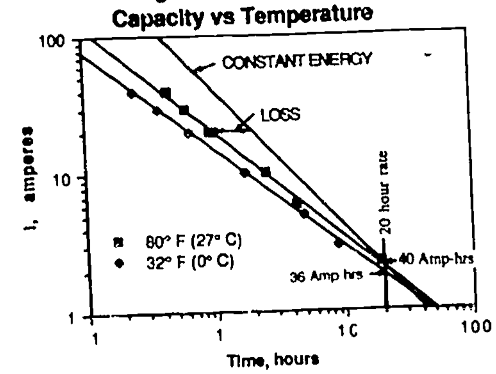



**Figure 2: Gel Cell Capacity vs Temperature**



**Discussion**

We have tested two types of electric wheelchair batteries and determined the capacity (distance of travel per charge) under room temperature and freezing conditions. At 0 °C the data shows that there is a loss of capacity of 14 ampere-hours for the wet cells and 4 ampere-hours for gel-cells. However, the gel cells have a room temperature loss of 20 ampere-hours due to the lack of diffusion of the gelled electrolyte. Clearly, the wet cells are the batteries of choice when considering distance of travel under high and low temperature conditions.

Other considerations such as cost and overall life of the batteries are important. The life in cycles of deep discharge for gel cells was investigated in Ref. 4, and found to be lower than manufacturers' claims when used with wheelchairs. Our experience is that the wet cell battery has a longer cycle life than gel cells and is so much lower in cost that it is the most economical choice in terms of cost per cycle. Previously, the only advantage for the gel cell was that it was the only battery that airlines would accept for transport. However, in 1990 the Department of Transportation issued rules and regulations (5) concerning nondiscrimination on the basis of handicap in air travel. These new regulations state that, "carriers must accept battery powered wheelchairs, including the batteries, packaging the batteries in hazardous materials packages when necessary."

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Address: UVa Rehabilitation Engineering Center, P.O.Box 3368-University Station, Charlottesville, VA 22903.

# Seating Adaptations for Agricultural Equipment

Therese M. Willkomm
The Easter Seal Society of Iowa, Inc.
Farm Family Rehabilitation Management Program
Des Moines, IA

## Abstract

Approximately 48 percent of farmers with disabilities have been affected by mobility impairments. These impairments include spinal cord injuries, back injuries, amputations, and neuro-muscular disorders. As a result of such injuries/illnesses, sitting tolerance is often affected. Operating a tractor can cause additional pain and discomfort from the mechanical shock and vibration experienced in the tractor seat when performing "off-road" work tasks. Modifying tractor seats for various disabilities is often challenging due to the unique needs of the operator and the varying differences in make and model of agricultural equipment. The purpose of this paper is to discuss problems associated with making seating accommodations for persons with disabilities and potential solutions for overcoming problem areas. The solutions discussed are based on seating modifications that were made for 12 farmers with disabilities served by The Easter Seal Society of Iowa's Farm Family Rehabilitation Management Program.

## Background

Over 20 years ago, the first rural and farm family vocational rehabilitation program was established at the University of Vermont Extension Service. In 1979, the Breaking New Ground Resource Center at Purdue University was established to share information on agricultural worksite modifications for farmers and ranchers with physical disabilities. In 1986, The Easter Seal Society of Iowa's Farm Family Rehabilitation Management Program was initiated and has since served over 450 farm families affected by physical disabilities.

As a result of the 1990 Farm Bill, an amendment to provide education and assistance to farm families affected by physical disabilities was passed. There are now 10 states which, through the State Extension Service AgrAbility Demonstration Grants, are assisting agricultural producers in continuing to farm or ranch with a physical disability.

Many agricultural worksite accommodations are constructed on a trial-and-error basis. There has been very little research conducted on specific types of farm machinery modifications for specific types of disabilities. Furthermore, there are very few standards or guidelines for constructing specific types of farm machinery modifications.

For an "able-bodied" farmer, a good tractor seat must meet the following criteria (Koutsky, 1978):

1. Provide the operator with a comfortable and controlled seating posture.

2. Reduce mechanical shock and vibration transmitted to the operator.

3. Position the operator, relative to the machine, to provide adequate vision allowing him to safely and efficiently perform all of his work functions.

4. Position the operator to provide ease and non-fatiguing access to machine controls.

5. Restrain the operator within a safety zone in the event of collision or rollover of machine.

## Statement of the Problem

Human factors engineering and machine design incorporate these basic functions in today's manufacturing of operator seats for agricultural equipment; equipment generally built to suit the able-bodied. These functions must also be provided for operators affected by physical limitations. Unfortunately, there are several obstacles with which to contend in the pursuit of making seating adaptations for agricultural equipment. These obstacles include:

1. *The unique nature of the disability*: As the effects of disabling conditions vary from individual to individual. each person requires unique adaptations. Some seating adaptations which are beneficial for one farmer may be detrimental to another farmer with a different type of disability or even for an able-bodied farmer who intends to operate the same equipment.

2. *Space considerations:* The space restriction in various makes and models of agricultural equipment can cause problems in making accommodations for physical limitations. Common space problems include: inadequate space to allow the seat to swivel for an operator with a back injury to see behind the machinery when doing field work tasks; lack of space to mount an independent seat suspension unit; and lack of space necessary to install a seat with adjustable arm rests.

3. *Obtaining replacement seats:* This proves to be particularly difficult as many manufacturers of tractor seats limit production to the number of tractors being manufactured. These independent suspension seats must therefore be ordered part-by-part and later assembled; a process which can take several months. At present, there are only two models of fully assembled replacement independent suspension seats available; the Maxxum air suspension seat from Case International, and the Grammer Air Suspension Seat. These seats can be retrofitted for various makes and models of equipment. Unfortunately, these seats will only fit on a flat base.

## Approach

In solving the unique seating requirements for operators with physical limitations, it is important to analyze the operator's specific needs, particularly:

1. Balance: Does the operator have good upper-body balance? This is important in determining the type of seat cushion that will be needed and whether a chest seat belt will be needed.

2. Rotation of upper torso: Does the operator have the ability to turn at the torso to see behind the tractor when performing field work? This is important in determining if any additional accommodations will be needed to see behind the machinery.

3. Reaching: Can the operator reach the hydraulic controls, foot controls, steering, or Power Take Off (PTO) control? Again, this is important in determining whether further accommodations will be needed.

It is also important to analyze the operator's current seat arrangement to determine the type of suspension that the seat has as well as the make and model of the tractor. It is also important to determine whether there is a flat area to mount a new seat suspension unit and whether the space available can accommodate the needed seating modifications. This is done by measuring the distance from the seat to the steering wheel, controls, ceiling, and floor.

After carefully analyzing the unique needs of the operator and the dimensions of the equipment, the following solutions can be explored in making the necessary accommodations.

Seat Suspension: In making accommodations for mechanical shock and vibration it should be noted that, if the current suspension is hydraulic and does not operate independently of the equipment, there is little that may be done to improve its vibration and shock absorption aside from an overhaul of the hydraulic suspension. If the current suspension unit is a mechanical seat suspension and is mounted on a flat base, an independent air seat suspension unit could be installed. Some mechanical suspension seats can be overhauled to increase their vibration and shock absorption.

Seat Cushions: Many farmers who have experienced back injuries need seat cushions that provide better back support. Recent human factors engineering has yielded great improvements in seat cushion design in the areas of adjustable lumbar support, adjustable thigh support, and adjustable arm rests. Seats in older model equipment can be replaced with newer style ergonomically-designed seat cushions. These cushions can be purchased through local agricultural machinery dealers. Replacement seats for equipment without cabs can be obtained through agricultural equipment dealers and farm supply stores.

When selecting replacement seat cushions, farmers with back injuries prefer a cushion that allows them to frequently change positions and turn their legs at least 45 degrees when rotating their upper torso. This movement is necessary in order to see behind the equipment when performing work tasks. Farmers who have experienced a high-level spinal cord injury prefer a seat which is more contoured to their body, as these types of seat cushions provide better upper-body support and help the operators feel more secure in accommodating for their lack of balance. Many farmers who have experienced back injuries stated that they do not like a contoured seat because it restricts their ability to rotate their upper torso.

When mounting seat cushions to the existing suspension unit, 1/8-inch plate steel can be used to securely fasten the seat pan.

Other Accommodations: A swivel mechanism may also be of use as it allows the operator's seat to turn up to 45 degrees in either direction when performing tasks that require one to see behind the tractor. Although the swivel mechanism can be installed under the seat pan, not all tractors will accommodate it. Swivel mechanisms can be obtained through either farm equipment dealers or local junkyards.

There are various accessories available to eliminate the need to turn one's body to see behind the tractor when hooking up to equipment or when performing field work. Additional mirrors can be mounted inside and outside the tractor to provide a wider field of vision. Automatic hitching devices can allow the operator to be off as much as 2 feet when hooking up to equipment.

Farmers who have experienced high-level spinal cord injuries may need a chest seat belt due to lack of upper body stability. These belts can be fastened to the back of the seat cushion.

One farmer who experienced a back injury needed a reclining seat. The reclining mechanism was obtained from a Toyota car seat. The original seat on the tractor was removed and a Toyota car seat was mounted on the existing seat suspension unit.

When making accommodations to the tractor seat, there exists the possibility that the accommodations might interfere with effective use of the clutch, brakes, and steering wheel. As it is vital that seating accommodations not interfere with the operator's ability to safely and effectively operate the equipment, further accommodations may be needed. A telescoping tilt steering wheel in the tractor is one solution which can be utilized. In addition, the pedals could be extended if the suspension unit raises the seat too high. However, in a tractor cab, it is very important that sufficient head clearance be allowed for jarring in which the operator may be raised up out of the seat.

Few farmers affected by spinal cord injuries have complained of skin breakdown when operating farm machinery. Some believe that this is because the constant shock and vibration experienced in the operator's seat acts as an artificial massage and helps increase blood circulation. Some farmers stated that they use their wheelchair cushions on the tractor seat for added protection. One farmer cut a relief area in the tractor seat cushion to accommodate a bony prominence. A seat cushion that is custom-made to conform to one's body, such as the Contour-U seat, may be detrimental to the operator since all shock and vibration cannot be completely absorbed and the cushion must allow for the operator's up and down movement when performing tasks over rough terrain. Custom form-fitting cushions might restrict this movement.

Seat Adjustment Accommodations: Independent suspension seats often have a height and weight adjustment feature which automatically adjusts to the operator's weight when the tractor is turned on. The height of the seat is often adjusted via another control. Thigh support and back support in the cushions are usually adjusted by turning a knob. Another control adjusts the fore and aft of the seat which brings the seat closer to, or further away from, the steering wheel. If the seat does not raise high enough, a taller mounting bracket could be installed under the suspension unit. If the seat does not come forward enough, the seat slide mount could be moved forward or a new fore-aft adjustment with a longer slide could be installed.

### Implications & Discussion

As more agricultural producers who have been affected by various types of limitations choose to operate agricultural equipment, more seating adaptations will be needed. Unfortunately, many agricultural producers cannot afford to buy a new tractor with an ergonomically-designed seat. An agricultural producer's greatest asset in his/her business is him/herself, therefore investment in a safe and effective operator's seat that will decrease potential secondary injuries and increase productivity makes good business sense.

As agricultural producers are encouraged to continue farming as a way of life, accommodating physical limitations in the operator's seat will prove to be extremely important for those operators affected by mobility impairments. Agriculture continues to become less labor-intensive, which results in a more viable occupation for individuals affected by severe disabilities. Research on seating adaptations for agricultural equipment is needed. Manufacturers of seats for agricultural equipment need to realize that there is a growing market for fully-assembled human factors replacement seats.

Comfortable seats sell tractors. "The role of engineering is to make sure that the marketing specifications for the seat are met not only to the satisfaction of the marketing department, but more importantly, to the satisfaction of the end user, the customer." (Stikeleather, 1981) Ergonomically-designed seats that are fully adjustable benefit everyone, not just individuals with physical limitations. Agricultural producers and rural rehabilitation technologists need to continue sharing their experiences regarding seating accommodations with: producers who have experienced new limitations, agricultural equipment manufacturers and dealers, and other rural rehabilitation technologists.

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### For more information, contact:

Therese Willkomm
The Easter Seal Society of Iowa, Inc.
Farm Family Rehabilitation Management Program
P.O. Box 4002
Des Moines, IA 50333
(515) 289-1933

# Functional Considerations for Portable Ventilator Users

Denise Wagner, Joe Lynott, Paula Kolar*, Kitch Barnicle
National Rehabilitation Hospital
Washington, DC
*ECRI, Plymouth Meeting, PA

## ABSTRACT

As part of an ongoing evaluation of portable ventilators, many problems related to the use of these devices were identified. It was discovered that many of the problems associated with home care ventilators are related to the accessories used in conjunction with the portable ventilator. This paper discusses issues that users and clinicians should be aware of when using a ventilator and its accessories on a wheelchair.

## INTRODUCTION

Many individuals who use portable ventilators have extensive medical and assistive technology needs. The effort and planning necessary for an individual to return to the home setting can be an overwhelming experience for the individual and their family. Because there are so many factors that must be considered when returning home, developing an adequate means of transporting the user to activities outside the home is often delayed or ignored due the complex nature of the hospital/home transition.

The importance of mobility to a ventilator user's quality of life cannot be overestimated. The equipment needs for the mobile user depend a great deal upon the amount of time the ventilator is used. If the ventilator is only required at night, only space and electricity needs must be anticipated when the user is planning to sleep away from home. However, if the ventilator is required 24 hours a day, safe movement of the ventilator, its batteries, the breathing tubing, manual resuscitator, and any other necessary accessories must be anticipated with every movement of the user. For overnight or lengthy day trips, back-up power sources and other equipment may also be needed.

## WHEELCHAIR MOBILITY

### Ventilator Trays

A ventilator tray that carries a portable ventilator, the ventilator's external battery, and possibly the wheelchair's batteries can be attached to a power or manual wheelchair, providing mobility to the user. The tray is mounted to the wheelchair's frame under the seat. Several sizes and types of trays are available commercially to accommodate different wheelchair models, and any additional equipment that must be transported. Some homecare agencies or dealers prefer to have the trays custom made or to modify a commercially available tray.

The ventilator and its external battery sit on the tray. Trays may either be fixed or they may slide out from beneath the wheelchair for easier access to the batteries and ventilator. Most trays have a lip around the edge of the tray to prevent the equipment from falling off. It is advantageous for the ventilator tray to have a metal divider or a separate box for the battery, which separates the battery from the ventilator so that fumes emitted by the batteries are not taken into the ventilator's air intake manifold. Fumes which are taken into the ventilator's air intake manifold will be delivered to the user's respiratory system and can cause permanent damage to the air passages and lungs. Drainage holes in the tray will also reduce the risk of damage to the ventilator caused by acid spills.

Securing straps are necessary to hold the ventilator in place and prevent it from tipping. Securing straps must not interfere with the function of the ventilator by obstructing the view of alarm indicators or interfering with the opening or closing of a front panel if one exists. Likewise, securing straps must not interfere with the function of the breathing tubing by placing tension on the tubing or by kinking it. All ventilator trays are not designed with straps, drainage holes, or dividers. These features may have to be added by the user or supplier.

Ventilator carts are available for power base wheelchairs that do not have sufficient space beneath their seats for a tray. This option is not optimal since the cart adds a significant amount of weight to the rear of the system and significantly increases the turning radius of the wheelchair.

### Tubing

Breathing tubes should be secured to the ventilator, the user, and the wheelchair if one is used, because of the risk of accidental disconnection while the wheelchair is moving. Tubing should be secured by straps to the wheelchair or to a support arm along its length between the ventilator and the patient so that it is not caught while passing objects such as door handles, chairs, or tables. Tubing may be accidentally disconnected by a closing elevator door, the foot of someone behind the wheelchair, or by reclining the wheelchair too far and compressing the apparatus. For these reasons, the orientation of the ventilator, facing forwards or facing up, must be considered. The safest position for each individual's ventilator should be selected according to his typical activities. The characteristics of the ventilator and tray may dictate the ventilator's orientation. For example, some ventilators have power cords which interfere with placing the ventilator in certain desirable orientations.

### Accessories

Accessories such as a heater, humidifier, oxygen, suction device, and a manual resuscitation bag may be necessary. While a jar type humidifier provides excellent humidity, it is unsafe to use during transit because of the risk of spills. Spilled hot water can harm the user or damage electronic controls. Heaters only work properly when attached to a humidifier. An artificial nose, which may also be called an in-line condenser or HME (heat moisture exchange device) is practical and safe for use while mobile and offers sufficient heat and humidification for most ventilator users. An artificial nose is unable to supply the high levels of humidity commonly supplied by jar type humidifiers. There are many different artificial noses available. Users may want to experiment with different brands to determine which HME meets their humidification needs.

Oxygen is portable in either gas or liquid form. Canisters of oxygen gas or containers of liquid oxygen should be secured directly to the frame of the wheelchair. Many ventilator users find the liquid form more convenient because of its reduced bulk and weight. Depending on the user's needs, liquid oxygen may be more expensive for full time use.

For individuals who require periodic suctioning and/or manual ventilation, accessories such as portable suction machines, suction kits, and manual resuscitators may be secured on the tray under the wheelchair, or hung in a bag behind the wheelchair.

Car or Van Travel
Whether or not a wheelchair is used, if the ventilator is used while traveling in a car or van, it must be secured. The vehicle's seat belt or tie down system may serve this purpose. Also, a cigarette lighter adapter should be used when in a motor vehicle to conserve the external ventilator battery power by connecting to the car battery.

Batteries
A portable ventilator has three possible sources of power. These are an internal battery, an external battery, and A.C. or line power. The ventilator should be plugged into the wall whenever possible in order to conserve both battery sources. The internal battery can be expected to last 30 minutes to one hour when fully charged. For that reason, it should be reserved for emergency use and a fully charged external battery should always be available. Internal portable ventilator batteries are lead acid batteries. These batteries slowly discharges over time when not in use. Therefore, if a ventilator is not used frequently, it should remain plugged in to A.C. power to prevent accidental discharge.

The time the external battery lasts depends upon the properties of the battery and how the ventilator is used. If used continuously, with high breathing rates and volumes, the battery is drained quicker. Portable ventilators utilize 12 volt, deep cycle, external batteries. The battery may be sealed lead acid or gel. Lead acid batteries generally last longer but require more maintenance. Gel batteries do not carry the risk of acid spill and are allowed on aircraft but they will require more frequent recharging. Battery maintenance activities, including charging, should be performed in a well ventilated area away from the ventilator user. This is especially important when oxygen is in use. When connecting the battery charger to either kind of battery or opening the caps of a lead acid battery to check the fluid, care must be taken to avoid touching both poles of the battery simultaneously as this may cause sparks, a fire, or an explosion.

Battery Chargers
Each ventilator requires an external charger which is compatible with the type of battery used. Care should be taken in understanding the charging procedure. Certain ventilators do not charge the external battery while they are plugged into a wall outlet unless they are in a "charge" mode.

## DISCUSSION

Many details must be addressed before a ventilator user can interact safely with his or her community. With proper user and caregiver preparation and training most mobility obstacles can be eliminated. When the time comes to choose a means of mobility it is important to conduct a comprehensive assessment of the user's technology and accessibility needs.

## ACKNOWLEDGEMENTS

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Denise Wagner
REquest REC
National Rehabilitation Hospital
102 Irving St., NW
Washington, DC 20010-2949

# 7.1 Safe Software in rehabilitation mechatronic and robotics design

**William Harwin and Tariq Rahman**
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

### Abstract

Software developed to fulfil the needs of research is usually written with the intention of gathering data either directly or as part of a device. Even well designed software may contain flaws that prevents use in anything other than the laboratory. In this paper we will consider some methods available for improving the safety levels of software, in particular those relating to robotics applications, and discuss the practices of safe software design in rehabilitation.

Whereas safety issues should not obscure research questions, if they are considered early in a project it will result in fewer difficu ties and a higher level of safety should the project move on to a technology transfer phase.

### Background

What is in a robot

The term robot derives from the Czech for slave and has been applied to any number of machines ranging from the mythical mechanical intelligence of Star Wars to the domestic washing machine. Rather than a definition we give some examples of what might be considered rehabilitation robots. Few would question the manipulators, and position controlled robot arms designed or adapted to rehabilitation applications and an incomplete list might include the technologies known as MANUS, DEVAR, REGENISIS and MASTER [2]. However the wheelchair mounted manipulator developed by Jim Hennequin does not contain a computer [4]. Likewise the top range Permobile wheelchair has an onboard microprocessor and is effectively a 7 degree of freedom manipulator. A powered prosthesis orthosis or exoskeleton can be invested with machine intelligence and considered a robot, as can a sophisticated functional electrical stimulation arrangement, all be it that the motors are rather more intimately attached. There is no reason why a powered mouthstick should not be viewed as a robot! Thus the term 'robot' is general and can probably be interchanged with the word 'mechatronic' without compromising meanings.

"A safe robot doesn't move"[1]

Absolute safety does not exist. Invariably it is a compromise between benefit and perceived risks. The role of the engineer is to maximize the benefit while keeping costs and risks at an acceptable level. In rehabilitation this problem is made harder by the small market and the potentially high levels of risk. The present generation of robot devices will happily spill hot coffee into your lap if given the instructions to do so. The issue is whether the benefit of a refreshing brew is worth the risk of giving the wrong command to the machine. However with a complex technology the risks vairy dependent on the hardware, software, lack of maintenance or training.

The software does not exist in isolation. Software requires hardware and possibly also an operating system. Figure 1 shows the interconnections between the software, computer, sensors, actuators, user and environment. Safety of the physical components, the interface electronics, computer(s) and sensors can be assessed with techniques such as failure mode and effect analysis (FMEA), fault tree analysis (FTA), hazard and risk analysis, and reliability modeling. For examples see [1], and the military handbook 217 [5]. Figure 1 includes a representation of active controls since a control may transfer power to the user, a principle widely known as extended physiological proprioception (EPP).

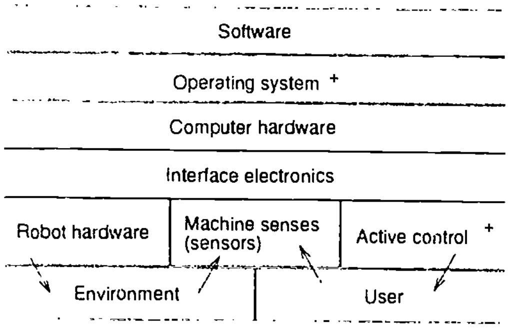


Figure 1: Hierachiy of software control

Safety at all levels is not the consequence of quality, rather it requires effort to identify risks and minimise the consequences. Safety is a forum where concern should be voiced, identified and addressed.

### Methods of software safety

A design dilemma. Complexity cost trade-off

The relationship between cost, functionality, reliabil-

1 Quote attributed to Hoc Kwee of The Instituut voor Revalidatie Vraagstukken, Hoensbroek, Netherlands.

**Table 1:**

| | SPADE Pascal | ISO Pascal | ADA | Modul a2 | C | Structured assembler |
|---|---|---|---|---|---|---|
| Prevents memory overwrite | ✔ | r | r (✔) | r (✔) | ✕ | r |
| Has a consistent maths with the consequence of overflow, underflow etc. well defined | ✔ | r | r (✔) | r (r) | ✕ | r |
| Has strong data typing | ✔ | r | ✔ (✔) | r (✔) | ✕ | r |
| Exception handling | ✕ | ✕ | ✔ (✔) | r (r) | r | ✕ |
| Will detect stack or heap overflow and similar exhaustion of memory | ✔ | r | ✕ (r) | r (r) | r | ✔ |
| Separate compilation and type checking between modules | r | r | ✔ (✔) | ✔ (✔) | ✕ | ✕ |
| Has language constructs that are well understood | ✔ | ✔ | ✔ (r) | ✔ (✔) | r | ✕ |

ity and safety is complex and not as linear as indicated in figure 2. This figure does however represent the de-

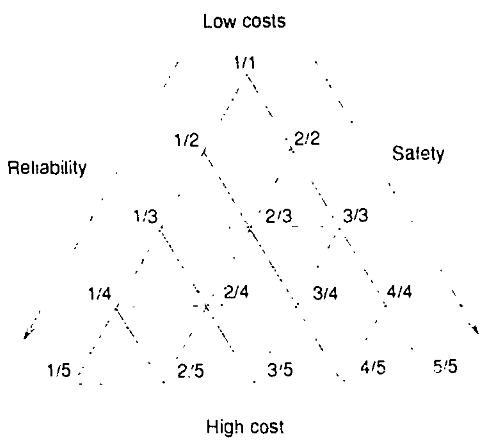


Figure 2: Reliability-Safety-Cost triangle

sirability of having duplex, triple and multiple units available. Thus a system that requires 1 out of 5 units to function is highly reliable, whereas a 5/5 system is considered more safe. The redundancy can vary from multiple processor systems such as the Airbus fly-by-wire airplanes which requires a majority verdict among the 4 onboard computers (3/4), to multiplexing the transducers on a joystick to guard against wire or position failure.

Most rehabilitation equipment appears near the apex of the triangle. In rehabilitation robotics several projects use the practical compromise of installing a watchdog that ensures the software is in control.

Formal methods

Formal methods are increasingly used to define the structure of a computer program and to evaluate that structure once code has been written. Formal methods have a solid foundation in set theory and this can be used to make predictions about the interaction of differing elements of the code. The two most popular languages for writing a set of specifications are Z and VDM. Other languages include OBJ, META-IV, Structured Analysis Design Technique (SADT) and LOTOS.

Once a formal specification has been written it can be validated to ensure it has correctly captured the requirements. The next stage is to verify the specification to ensure it is consistent. It is also possible to verify the specification of one part of the system with the specification of a second part of the system. For example one part of a formal method would ensure that joint velocities are not to exceed a given level and the specification of a straight line motion may specify an infinite joint velocity. The formal methods do not dictate how the program will be written rater they are used to identify inconsistency before coding begins.

Software languages

Once code is written software tools are available to do static code analysis (ensuring that variables are initialized) or identifying loop invariants (variables that should not be effected by the loop). This assumes the choice of language and table 1 is a composite of the results of Cullyer, Goodenough and Wichman [3] on seven desirable characteristics of a safe language.

A ✔ in the table indicates that the feature is acceptable, an r indicates that the feature is available but there is still a risk and an ✕ indicates that it is absent. Software for safety critical applications is often written in a safe subset of a language thus the language SPADE is a subset of ISO pascal. Bracketed marks for ADA and modula2 show the results for a safe subset of these languages.

Cullyer, Goodenough and Wichman refused to rate C++ in their paper because any C program is a C++ program so was already rated. Pragmatically C++ is likely to become a widely used language and a safe subset may be identifiable. C++ has desirable characteristics in its strong data typing, independence between modules and, by overloading the bracket operator, prevention of memory overwrites. For applications requiring high security it is unlikely that a C++ subset will match the qualities of SPADE or the ADA and Modula2 subsets.

Legislative guidelines

In the USA all rehabilitation devices come under the auspices of the Safe Medical Devices Act as administered by the Food and Drug Administration (FDA) and although this legislation is aimed at approving devices to market, rehabilitation software developers should be aware of how this legislation is organised.

The FDA recognises three levels of risk to a person. 1) minor, little risk of injury either direct or indirect, 2) moderate, life threatening or causing permanent impairment or damage and 3) major, risk of death. The Act requires a manufacturer to provide 'paper trails' for a devices following sale. These paper trails allow data to be gathered to establish levels of safety and assessing the manufacturer's claims. In robotics part of the paper trail could be a data trail similar to that in place in DEVAR, whereby every event that occurs in the system is logged into a file [4]. Such a monitoring scheme could record all the robot's movements so data could be collected on safe practice and, should a serious malfunction occur, the conditions that cause the malfunction could be reconstructed.

The FDA does not specify methodologies and they are likely to use existing standards when they need to assess new devices. The current standards relating to software design in the USA are ANSI [6] 828,829 and 730 and the military standard 882B [5].

The user interface

An important consideration in rehabilitation robotics safety is training the user to a point where the operation of the robot is transparent to achieving the task. The user should ultimately be able to have a good concept of when the robot will move and the consequence of that movement.

Given the complexity of the robot it is usual to experiment with an input and judge the consequence of the action from the resulting movement but under some conditions this strategy is not appropriate.

The user interface must be reliable; that is if the user intends to initiate a particular command there must be a high probability of the correct action being initiated. For example it may be easy to achieve a reliable interface for a spinal cord injured person using residual hand motions or voice command but the same reliability is achieved at the expense of time to register a command for a person with severe athetoid cerebral palsy using a keyboard or switch combination.

## Discussion

This paper has necessarily been a superficial review of considerations in software safety. In rehabilitation robotics and mechatronics there are possibilities for safety linked to research. All data comes to the computer via sensors and although these sensors deliver appropriate information the machine is not able to interpret it correctly. Thus although the computer may listen and see the robotic device spilling coffee into the user's lap, this fact will not register. Modern pattern recognition techniques may be able to improve machine intelligence! Research on the machine interface is needed and EPP principles, whereby force information is reflected back through the interface, offer a promise but the safety of EPP devices is as important as the safety of the robot it controls.

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William Harwin, ASEL
P.O. Box 269,Wilmington, DE 19899,U.S.A

# INTERACTIVE ROBOTICS IN A CAD WORKSTATION

P A Finlay, J-M Detriche, G Bolmsjo, T Jones, and R D Jackson

## ABSTRACT

The paper describes a CAD workstation designed for individuals who use wheelchairs for mobility and who have little or no upper limb function. The workstation includes a general-purpose robot for paper handling and other tasks.

## BACKGROUND

A project on the development of a robot-assisted workstation has recently started under the European Community rehabilitation engineering initiative TIDE (Technology for the socio-economic integration of disabled and elderly people). The aim of the project is to build a self-contained vocational workstation for a disabled user. The workstation is to be used for CAD and desk-top publishing and other graphical layout tasks, although in its initial form will target CAD applications. The project has been given the acronym RAID - robot for assisting the integration of disabled people. The initial, pilot, phase of the project is scheduled for completion in early 1993.

This paper describes the state of the project shortly after it began in December 1991. The project does, however, build both on previous work on office workstations accessible to people with severe upper limb motor disability [1,2] and on the substantial experience of the partners in the RAID consortium in this field. The partners have experience in the design of workstations for domestic, office and workshop tasks [3,4,5]. The paper is largely based on the user requirements specification which has been prepared following input from all members of the consortium.

## STATEMENT OF THE PROBLEM

Design office work using CAD packages is an activity which is accessible to many people with severe motor disabilities. Applications can vary from mechanical engineering design, through electronic circuits and microcircuits to the field of desk-top publishing. Computer access methods are already well developed and improving fast and openings for people skilled in computer-assisted design methods are likely to grow. Although much of the work in a typical design office is screen-based, some interaction with books, drawings and other methods of communication is essential. For this interaction, a desk-top robot can offer a general-purpose solution. The RTX robot will form the basis of the workstation.

The system is intended for users who use wheelchairs for mobility, but who have insufficient upper limb functions to be able to operate a computer workstation unaided. They should have at least two degrees of movement available. Typical interface methods are joysticks, roller balls and chin sticks. It is anticipated that many users will operate the workstation from wheelchairs, using the wheelchair controller via an infra-red link.

## DESIGN CONCEPT

The user input and feedback will be via a PC, using a single screen. To allow multiple program control, including control of the robot and other peripherals, a graphic environment such as Windows will be used. The robot will operate under direct or pre-programmed control, using sets of defined procedures to perform repetitive tasks. The main tasks now being planned for robot assistance are those in which the members of the consortium have established prior experience.

These tasks are paper handling, including collation and filing, selection of manuals and their transfer to a reader board, page turning and telephoning. Some personal functions, such as fetching a mouthstick, pouring and serving drinks, will also be available on the RAID prototype.

It is intended that the user should be able to start and stop working with RAID without the help of an attendant, although some supervision and help will be necessary in setting up the working environment. The workstation design will make it accessible to non-disabled users.

Safety of the robot system is a prime consideration. The workspace of the robot itself should not intersect the user space, but certain articles, such as a mouthstick, which can be held by the robot will have to reach the user. Special consideration will be given to procedures using articles which can reach the user's space. Ways of calling for assistance and an emergency stop under user control form part of the prototype definition.Evaluation and conclusions.

The limited timescale of the TIDE pilot phase means that the prototype workstation will draw mainly on tested hardware and software packages. Interaction with users during the design and construction stages will be via a reference group of potential users, five of whom are tetraplegic and two of whom have cerebral palsy.

A set of trials on the prototype workstation will be carried out by members of the reference group in early 1993.

## ACKNOWLEDGEMENTS

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**Contact:**
Dr P A Finlay
Armstrong Projects
49 Candlemas Lane
Beaconsfield
England
HP9 1AE.

# KINEMATIC ANALYSIS OF POWERED UPPER-EXTREMITY ORTHOSES

Carolyn R. Anglin, Douglas P. Romilly,
Raymond G. Gosine
Dept. of Mechanical Engineering

Cecil Hershler
School of Rehabilitation Medicine

University of British Columbia, Vancouver, B.C., Canada

## ABSTRACT

Achieving the functionality, strength and aesthetics of the human arm in a practical orthosis design is currently impossible. The most significant and necessary compromise is in the choice of available degrees-of-freedom (DOF). The accessible task space must be traded against the controllability, complexity, weight and cost of the device. Both extremes of the spectrum will lead to rejection of the device. Determining the optimal set of DOF analytically will not only allow a conclusive decision to be made but will permit many design iterations *before* a device is designed or built.

A survey of potential users as well as past surveys reported in the literature (1-6) were used to establish a set of task priorities. A motion analysis study will be performed to establish the movement of the arm and the corresponding changes in joint angles as able-bodied people perform the top-rated tasks. A kinematic analysis will be applied to this data to determine which DOF are needed to reach the target positions (e.g. table, mouth, reach). The research will attempt to identify both the "component" movements that form the basis of the tasks and the potential for coupling certain DOF.

## BACKGROUND

Since a wide range of upper limb dysfunction may exist in the disabled user population, it was deemed necessary to define a representative user profile for design consideration. Therefore, during the course of this research, the potential user of a powered upper-limb orthosis is assumed to have two completely flail arms while still retaining adequate range-of-motion. It is also assumed that only one arm will be provided with function.

Based on the survey results, the following task groups in order of priority have been defined as:

1. Reaching/ Picking up objects;
2. Personal Hygiene (brushing teeth, washing face, combing hair, applying makeup, shaving, scratching and blowing the nose);
3. Eating/ Drinking;
4. Holding the arm in a given position (keyboarding, TV remote, telephone, environmental control, painting);
5. Preparing food;
6. Toileting;
7. Turning pages; and,
8. Dressing.

While the ability to dress and toilet would contribute to greater independence, they have been deemed outside the realm of a practical orthosis. Transference to the toilet usually requires great strength (far above the orthosis design criteria) while dressing has been discarded due to its complexity and because it normally occurs only twice a day when a helper would normally be available. Vocational, educational and recreational activities have not been directly included. Many of the actions, however, are equivalent to the daily-living tasks listed and therefore may fall within the capabilities of the resulting orthosis.

In order to assess the required task space, the actions of able-bodied people executing representative tasks from task groups 1-5 & 7 will be recorded using two video cameras (see Figure 1). Reflective markers will be attached at each of the subject's joints as well as on the objects themselves to allow motion data to be collected.

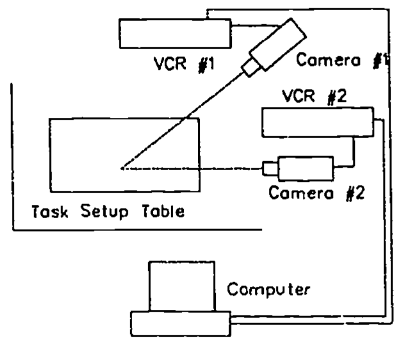


Figure 1: Motion Analysis Setup

The resulting images will be processed to reconstruct the movements in three-dimensional space (the software has been largely adopted from the Biomedical Engineering Laboratory at the University of Manitoba (7)). Stick figure diagrams and angle-time graphs will be used to analyze the data. Further studies will determine the component movements common to many tasks, with implications both for control and for actuation. For purposes of evaluation and comparison, the tasks will be repeated, where possible, with the recently designed Hugh MacMillan Rehabilitation Centre powered orthosis (8).

## STATEMENT OF THE PROBLEM

The objective of the project is to discover the optimal set of degrees-of-freedom required to achieve the tasks defined. There is currently no definitive answer as previous efforts to do so have been compromised by computer capabilities of the time, by not consulting the disabled population for task priorities, and by the lack of positional and path data specific to the tasks.

Building a powered upper-limb orthosis with too many degrees-of-freedom leads to an overly complex, costly and heavy design. Furthermore, if the device is too difficult or fatiguing to control it is certain to be rejected. If, however, the orthosis has too few DOF to perform critical functions it is also likely to be rejected. Therefore, the goal is to optimize this cost/benefit ratio in relation to the selection of DOF.

## PREVIOUS KINEMATIC ANALYSES

One method of approaching the problem is to develop a kinematic model of the orthosis. Much work has been done in the robotics field to produce forward and inverse kinematic solutions for common robot geometries. Unfortunately, unlike robotic manipulators, the human arm has restricted joint limits. The human wrist, for example, does not have the complete rotation that makes robotic endpoint positioning and orientation relatively straight-forward. Standard solutions therefore cannot be adopted.

Engen conducted a comprehensive motion analysis of able-bodied people performing table-to-mouth feeding, hair grooming, page turning, writing and diagonal reaching (9). Based on the results, the importance of providing and allowing shoulder movement was highlighted. The elbow, by contrast, can be fixed at a given location for a particular activity without much loss. It was also noted that pronation/supination and wrist flexion/extension should be powered to allow for finer movements. Engen's prototype orthosis was implemented with a high level of success. While further analysis was beyond the scope of Engen's work he recommended that it be given priority. The advance of computers makes that currently possible.

The complex three DOF shoulder motion were studied by Enger (10) with the objective of compressing the required motion into a single turn axis for prosthesis design. Using geometric relationships, a specially-designed mechanical device and stereometry, his team determined that a 45° turn axis would bring the arm from the side "table" position to the front "mouth" position. Elbow flexion (coupled with ulnar/radial deviation), forearm rotation, wrist flexion and grasp were incorporated into the prosthesis as well. Clearly this simplified the shoulder mechanism and control, but only allowed for eating-like activities.

Based on recording and rating the everyday activities of 17 able-bodied subjects, McWilliam (4) identified 180 tasks as the most important for daily living. The endpoints of each action as well as any essential paths were noted through observation (11). Using observation only, however, leads to a non-quantitative characterization of the task movements. Dressing tasks were also included, leading to a much different task space than for this project. A mechanical model was created to test various selections and combinations of axes against the task requirements, undoubtedly a time-consuming process. The resulting minimum requirements were: shoulder flexion/ extension, upper arm rotation coupled with abduction, elbow flexion, forearm rotation, wrist flexion and grasp (12). Since people with disabilities were not consulted to define the importance of the tasks, however, the applicability of these results is placed into some question.

It is clear, then, that a new kinematic analysis is required with specific motion data for tasks defined directly from the potential users and to take advantage of more advanced computer capabilities.

## APPROACH

A generic model of an upper-extremity system (see Figure 2) has been developed based on robotic analysis techniques. The grasping location is defined by supplying each joint angle to a forward kinematic transformation for the device. By then applying an iterative optimization routine to this model, the angles corresponding to the closest approach to a desired point, within the joint limits, can be discovered.

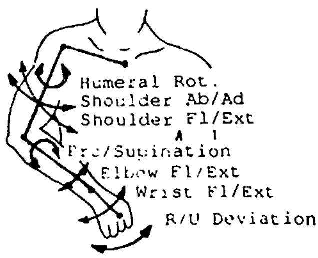


Figure 2: Upper-Extremity Model

Key points will be tested to determine the range of motion of the "arm" given the degree-of-freedom configuration and joint limits being analyzed. The primary focus will be on a) the table level, b) the mouth level and c) the reach forward position. The underlying assumption is that if the user can reach each of two points then some path can be found between those two points. This assumption will be verified at a later point, but means that the orthosis is not restricted to following the typical able-bodied path. No trunk or head movement is assumed so that such compensatory actions are not required of the disabled user. The secondary focus will be on reaching d) the top of the head, e) the table, in different orientations and f) towards the left and the right. Other extremes of the task space as defined by the motion analysis study will also be examined as necessary.

The resulting configurations will be checked for possible alternatives which achieve the same endpoint and whether the configuration accounts for obstacles such as a table. Sensitivity to the exact positions tested as well as the sensitivity to limb segment lengths will also be investigated. Joint limits will be adjusted to determine minimum requirements.

Coupling of individual DOF is a powerful way to decrease the number of degrees-of-freedom while still maintaining functionality. Potential relationships and "component" movements will be derived from the stick-figure and angle-time graphs generated from the motion analysis. Three-dimensional plots will be constructed of the task space in order to define the motion envelope for both single and multiple tasks. The number of degrees-of-freedom will be successively reduced until the minimum possible has been established for satisfactory performance over a range of tasks.

In addition to videotaping the typical motions required to perform the tasks, those tasks that can be simplified with common daily-living-aids, particularly eating and drinking, will be videotaped. If the kinematic analysis demonstrates that fewer DOF are then required, this trade-off will be seriously considered.

As a final application of the kinematic analysis, the Hugh MacMillan orthosis will be analyzed against the task requirements to evaluate its level of mobility and function.

## DISCUSSION

Powered upper-limb orthoses have numerous benefits. These include increased independence for the user, an increased sense of dignity and worth and a reduced burden on caregivers. The device will be readily discarded, however, if it is not functional and reliable or if it is too inconvenient, tiring or costly. The development of an orthosis based on a sound task and kinematic analysis will increase the functionality of the device and lead to an increased chance of acceptance by the end user.

Our team's final goal is to design a new powered upper-extremity orthosis. Five prototypes will be built and then tested in clinical trials. As a preliminary step, two Hugh MacMillan orthoses have been built to fit one of the authors. One of these will be modified to incorporate incremental design improvements. The modified version will be compared to the original design for both subjective and objective evaluation. The experience gained will be directly applied to the development of the new powered upper-extremity orthosis.

## ACKNOWLEDGMENTS

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*Contact Address:*
Carolyn Anglin
Dept. of Mechanical Engineering
University of British Columbia
2324 Main Mall
Vancouver, B.C.
V6T 1Z4
*Tel:* (604) 822-3532
*FAX:* (604) 822-2403
*email:* Carolyn_Anglin@mtsg.ubc.ca

7.4

# THE SELECTION OF ENVIRONMENTAL CONTROL SYSTEMS

J. Scott Bentham, William D.S. Brereton and §Richard A. Sapacz
Rehabilitation Engineering Department,
Health Sciences Centre, Winnipeg, Canada
§1010 Sinclair Housing Inc., Winnipeg, Canada

## ABSTRACT

Choosing or designing a suitable environmental control system to meet the needs of people with severe disabilities requires careful consideration of the user's abilities, resources and changing needs. It was therefore decided, through consultation with consumers and health care professionals, to develop a strategy to address these needs. This process has been successfully applied to the design and installation of an environmental control system.

## BACKGROUND

For people with physical disabilities the past decades have seen a significant increase in community living options. The demand for these options has lead to the development of community based support services and to a rapidly increasing variety of technical aids. Individuals are leaving institutions to live in various forms of alternative housing such as group homes, co-ops, integrated apartments or private residences. Technical aids are vital to the person with a severe disability who is living in the community. The ability to control the immediate environment is the key to the independent organization of personal needs and activities. To meet this increased demand for technical aids, a large variety of environmental control systems (ECS) and peripherals ranging from the simple to the complex have become available.

## STATEMENT OF THE PROBLEM

With the increased variety of housing options and the expanding assortment of technical aids, advice for their selection and installation is constantly being sought by consumers and health care professionals (1,2).

The specific needs of a person with a severe disability will vary depending upon their immediate circumstance. A person with a recent high-level spinal cord injury has different needs for technical aids in a hospital environment than he/she will have in the community. Similarly, people with progressive neuro-muscular disorders may have an increasing dependence on technology to maintain their independence in the home. The evaluation and selection of appropriate equipment, given the changing needs of the disabled person, proved to be difficult.

For circumstances requiring minimal technical assistance there are several options, including single switch devices to interface with hospital nurse calls or to operate equipment such as telephones or TV's. For increased needs, ECS's can range from systems with advanced information storage and visual displays, to personal computer-based systems with near limitless potential. Some of these devices are extremely well built and reliable while others are of very poor quality. Price or expensive advertising is not always an indicator of quality or function.

## SOLUTIONS

The views of consumers, therapists, personal attendants and others were integrated to obtain a profile of the desirable characteristics of an ECS (3). This profile has been useful in the selection of environmental control products.

Operation of an environmental control by the user should be simple to understand and simple to use. The variety of switches commercially available ranges from basic push-button styles to the more complex, for example EMG or eye-motion switches. For use in bed, push-button type switches require accurate and secure placement within the user's target area. During sleep, user movements may cause accidental activation or may result in the switch being moved outside the target area. A sip/puff switch on a flexible mounting bracket reduces many of these problems. It can easily be adjusted for ready access by the user after he/she is repositioned in bed and is immune to false triggering.

From a wheelchair, the most convenient access to an ECS is a wireless remote control incorporating an appropriate switch. An encoded radio frequency remote control allows the user secured access to their system from anywhere around their home. The use of an infrared remote control requires line of site operation to the receiver, thereby limiting the user's mobility when operating their environmental control unit.

The actual sequence of switch closures used to operate the ECS should be consistent. A simple sequence is easier to learn and will quickly become second nature to the user. As an example, turning on a TV, telephone, or lamp should all use similar switch activation sequences.

Visual displays, available on most ECS's, should clearly show the current status of the system. There should also be auditory feedback to allow the user control of the ECS, for example from another room, without reference to the visual display.

Following the initial equipment set up, the system should require little attention from family members or personal attendants. Appliances, such as lights that interact with the ECS should be simple to control by others without having to follow a complex sequencing routine. Frustration for both the user and the personal attendant will result if, for example, the telephone dialer or TV channel memory is complicated to reprogram. The simple repositioning of switches may be required periodically, but frequent critical positioning of head pointers or sensors increases the responsibility of the user and can be a major cause of system rejection.

Consumer products are made to be cosmetically appealing as well as functional. An ECS packaged in an industrial box with a poor or unmatched finish should be no more acceptable in the home than a poorly packaged or unattractive stereo.

The ECS used in an independent living environment becomes a vital part of daily planning and activity. Reliability and servicing are therefore important attributes. The attendant call (which may be a buzzer or a telephone) should be adaptable to the user's input switch if the ECS is removed for repair or modification.

Installation of an ECS should not require major home renovation. The use of wireless interconnections such as X-10 light and appliance controls, and the use of standardized equipment can reduce the time required for installation. Less complex installations can be carried out without the help of technicians and engineers.

Standardizing the ECS used in a given geographical region has several benefits. Consumers can exchange their knowledge and experience concerning the system without referring back to therapists or engineers. Therapists can become familiar with the characteristics of a system and so become proficient at instructing users and even setting up systems.

Standardization of equipment that allows for flexibility to meet the individual needs of a variety of users will help ensure it's success. For example, the ECS that can control one or two lights and a TV in a nursing home should also be able to handle several lamps, appliances, telephones, TV's, intercom and door lock by the simple addition of peripheral equipment. Standardized pneumatic and paddle switches can satisfy the needs of many consumers. The benefits of standardization are many: retraining on different equipment is eliminated; financial savings are realized by expanding rather than replacing equipment; and those working with the individual become more proficient with the equipment. Systems that are too complex create their own problems by making professionals reluctant to work with them and by being confusing for the user. Complex or custom devices are best suited to those who cannot use standard equipment.

## AN APPLICATION OF THE SOLUTIONS

After reviewing many commercially available systems, and with regard to our expertise and financial limitation it was decided that our clients would best be served by designing and building our own environmental control system. The Environmental Select and Operate Micro-controller (ENSOM) is the heart of the ECS that was developed to meet the needs in Manitoba.

The ENSOM is able to scan from two to ten channels at an adjustable rate. It takes advantage of the X-10 POWERHOUSE for controlling lights and appliances. Many one and two input-switch peripherals available from various manufactures can be operated through the ENSOM. This enables the user to take advantage of specialized equipment that may be needed while retaining a standardized system. Based on the MC68705 micro-controller, the ENSOM can be reprogrammed to meet specialized needs where necessary.

## CONCLUSION

These guidelines for environmental controls have been developed through consumer and professional input and extensive community experience. The application of these guidelines has led to the successful installation of environmental control systems in recent years. The guidelines were also applied to the development of the ENSOM that has been in use for over two years. Follow-ups have shown that users and health care professionals in Manitoba have reacted with a high degree of satisfaction and acceptance.

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Scott Bentham
Rehab. Engineering Dept.
Health Sciences Centre
MH021-59 Pearl St.
Winnipeg, Manitoba
Canada, R3E 3L7

7.5

# AN INTERACTIVE ROBOT QUANTITATIVE ASSESSMENT TEST

R. M. Mahoney, R. D. Jackson
Cambridge University Engineering Department
Cambridge, England

G. Dargie
The Papworth Assessment Centre
Papworth Everard, England

## INTRODUCTION

The Rehabilitation Robotics Group at Cambridge University is working in conjunction with the Papworth Group Assessment Centre to identify and evaluate employment in the manufacturing industry which may be accessed by physically disabled individuals through the introduction of an interactive robot system [1]. An aspect of the overall employment placement process which is being addressed as part of this project is the assessment of the vocational skills of a potential disabled employee [2].

This paper describes the development of an interactive robot quantitative assessment test (IRQAT). The purpose of the IRQAT is to provide quantitative measures of an individual's ability to control a robot performing a rigidly defined task using a range of control approaches.

## BACKGROUND

Assessment of potential employees is common practice within industry. The Valpar tests [3] are typical quantitative assessment tests administered by evaluators to measure specific abilities of prospective employees. Although the results of these tests do not provide complete knowledge of an individual's aptitude for a particular job, they do provide insight that is useful when considered with other evaluation criteria.

Occupational therapists make use of assessment tests when evaluating the abilities of patients undergoing rehabilitation. The Jebsen Hand Test [4] and the Box and Blocks Test [5] are examples of tests developed to provide therapists with quantitative evaluation of manipulation motor skills. These tests are used as part of the overall evaluation of the individual and the experience of the therapist is critical for appropriate interpretation of results.

Assessment tests which have been developed for teleoperators used in space and underwater applications provide relevant input to a test for a rehabilitation robot system. Hannaford, et.al., [6] have identified two types of tasks used for teleoperator assessment: generic tasks and application tasks.

*Generic tasks are idealized, simplified tasks that are designed to test specific telemanipulation capabilities. Application tasks are designed as much as possible to mimic real-world uses for teleoperation* [7].

Hannaford, et.al., evaluated teleoperator performance using generic tasks on a sensored testboard. The tasks included peg-in-hole insertion, velcro attachment of blocks, manipulating electrical connectors, and manipulating a bayonet connector. A set of performance measures were evaluated to determine the effect of varied control capability on task performance.

NASA has sponsored several projects aimed at investigating the impact of end effector technology on telemanipulator performance [8,9,10,11]. NASA, however, has not standardized its approach to generic task assessment.

The Rehabilitation Robotics research community has made little use of standardized assessment tests of generic tasks. Evaluation of systems has been largely through a qualitative, application approach. The main source of evaluation results has been through surveys of operators of a system and of a trained observer during clinical studies [12,13,14 to name only a few].

A notable exception to this is the work of King [15]. King made use of a test platform consisting of goal positions to quantify the effect of various control axes on end effector positioning ability.

## PROPOSED ASSESSMENT TEST

The IRQAT is intended to provide a standard quantitative measure of an individual's ability to control a robot to perform a generic task. The design of the IRQAT is based on previous experience in adapting a robot system to interactively perform the Valpar Tri-level Measurement Test [2]. This was intended to demonstrate the concept of interactive robot control and did not result in a standardized test.

Figure 1 is a drawing of the IRQAT, which has been constructed out of wood and is designed to be conveniently stored and transported. The IRQAT consists of an output rack which holds ten wooden dowels of 0.25 inch diameter, a 40 inch high barrier wall, and an input rack with ten holes into which the dowels can be fitted. The tolerance of the holes is large so that the dowels fit loosely.

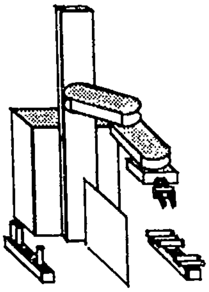

**Figure 1: Sketch of the IRQAT setup.**

The IRQAT will initially be used to evaluate an operator's ability to control an interactive robot system using various levels of menu control. This form of control is being investigated because a disabled operator will be physically unable to generate the input signals for direct coupling to the full degrees of freedom of the task.

A baseline standard for comparison will be determined from autonomous operation of the manipulator. This is in contrast to the standard determined by Hannaford in [6] which is based on performance by the unaided operator.

The CURL robot control language [17], controlling the UMI RTX robot, will be used to provide task level menu-driven control. CURL allows an individual to specify robot end-effector commands in terms of pre-defined objects and goals in a semi-structured environment. Task level commands, however, may be provided at various levels. For instance, a series of commands which would perform part of the IRQAT task could be as follows:

```
move right. (stop indicated through esc key)
move down. (stop)
grasp 40.
move down. (stop)
grasp 0.
move up. (stop)
move left. (stop)
```

And so on. These commands are relatively low level. The same sequence of motions could also be accessed through the following series of commands:

```
pick up peg1.
move above the barrier.
move above hole1.
pitch 0. (absolute position command)
roll 0. (absolute position command)
move down. (stop)
```

The second sequence of commands requires defining objects and locations in the environment and serves to demonstrate how the same task can be explained to the system in different ways.

For a highly structured system, the task level commands can become very concise. For example, the peg to hole task could simply be:

```
move peg1 to hole1.
```

Lower level command sequences are provided for several reasons. First, these lower level commands can be combined into higher level procedures as a task environment becomes more well defined. In addition, the lower level commands can be used to recover from highly unstructured situations, for example those which may result from failures (dropping of a peg, for instance).

The first trials with the IRQAT will be structured to evaluate how well an individual can plan a task at various command levels.

## DISCUSSION

The results of the interactive robot assessment test are intended to be used as an indication of an individual's aptitude for communicating effectively with a robot. These results will be considered in conjunction with other evaluation criteria to determine the client's suitability for using an interactive robot system to gain employment.

The IRQAT is potentially useful for evaluating other aspects of an interactive robot system. Changes to the control language, the manipulator, end-effector capability, control axes, or the interface device, for example, can be evaluated through administering of a standardized test of generic tasks.

The system of Figure 1 has been constructed and exact specification of the test protocol is being defined. Testing of a broad population of physically disabled individuals is planned over the next six months.

## ACKNOWLEDGMENTS

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**For more information, contact:**

R.M. Mahoney
Engineering Department
University of Cambridge
Trumpington Street
Cambridge, England
CB2 1PZ
email: rmm@cam.eng.ac.uk

# PROVIDING ON-LINE SUPPORT IN AN AUGMENTATIVE COMMUNICATION DEVICE

Clifford A. Kushler, Ph.D.
Prentke Romich Co., Wooster, Ohio

## ABSTRACT

An augmentative communication device has been developed which provides great flexibility and power to the system operator. A wide range of on-line support has been provided in order to assist the system operator in learning how to set up and use the device, and also to aid in learning the encoding system and the specific code sequences used to retrieve vocabulary items. These features have been added to assist the system operator when the speech therapist or main system support person is unavailable, and to minimize the amount of instructional time required for the system operator to become "fluent" in the operation of the device. They are also intended to help reduce the amount of support time required from the speech therapist or other clinician or support person. Other features have been designed to simplify the general operation of the device and to enable the system operator to more easily take advantage of the capabilities of the device.

## BACKGROUND

Augmentative communication devices have developed rapidly over the past few years. Systems have become more complex and powerful, offering a wider range of options and able to encode and store much larger vocabularies. As a result, the amount of time required to assist the system operator in becoming familiar with the operational features of such devices and in learning to efficiently retrieve these larger vocabularies has also grown significantly. This situation has arisen against a background of a shortage of trained clinicians with a strong background in augmentative communication. Other system support people are not generally trained professionals in the field, and thus require assistance themselves to master the operation and set-up of a communication aid. Even trained clinicians are faced with the prodigious task of becoming familiar with the operation of a wide variety of devices.

With this situation in mind, a new communication aid has been developed for which one of the design goals was to provide as much on-line support as possible. The intent was to provide support in a number of different aspects of device operation: the initial set-up of the device; becoming familiar with the basic operation and features of the device; learning and utilizing the stored vocabulary; maintaining the device and its vocabulary; and simplifying the utilization of the numerous features of the device in day-to-day operation to reap the maximum benefit from the device's potential to assist the system operator.

## STATEMENT OF THE PROBLEM

The process by which a system operator learns to communicate fluently and transparently using an augmentative communication device involves the acquisition of many new skills and a large body of new knowledge. The inherent complexity of the process of communication itself makes this unavoidable. The goal for any augmented communicator and his or her support team must always be to reach his or her maximum potential. The uniqueness of every individual then poses a problem which must be addressed: how to provide a communication system that satisfies the unique needs of a particular individual in a cost-effective fashion. Certainly, developing one-of-a-kind systems tailored to each individual's particular needs would be prohibitive in cost, and could eventually prove less effective if an individual's abilities or needs changed significantly over time. The alternative is to produce systems with a wide range of options which can be configured to each individual's needs. This unavoidably results in systems that are more complex.

## RATIONALE

Using such flexible systems to their best advantage requires a correspondingly larger number of options to be configured. Given that the trained clinician's time is such a valuable and relatively scarce resource, systems must be designed to minimize the demands placed upon the clinician's time. Equally important, the system operator needs to be able to learn how to use the system more effectively as quickly as possible, and when appropriate, to independently configure the system according to his or her own preferences. These goals can be achieved in several ways: 1) make it easier for the clinician to become familiar with the device; 2) provide a variety of basic applications / device set-ups, one of which can be selected and "fine-tuned" for a particular system operator; 3) provide a simple interface for configuring the system which is easy to use by both the clinician or support person and the system operator; 4) provide a mechanism to easily modify configurations as desired using a minimum of keystrokes; 5) provide readily available on-line help information; and 6) include powerful utilites for vocabulary access and maintenance.

## DESIGN / DEVELOPMENT

Many different features were designed and integrated into the device throughout the development process in order to achieve the goals outlined above. Comments and suggestions were solicited throughout the development process, both from a large number of augmentative communication specialists and from system operators using other devices. In the later stages of development, much helpful feedback was obtained from system operators involved in beta-testing the device itself.

Operator's Manual. While the operator's manual for a device obviously cannot be strictly defined as "on-line" support, it is certainly a vital part of the overall support picture for any device. Bearing this in mind, a great deal of effort was put into creating a manual that was both complete and simple to use and understand. The manual was designed to provide a concise introduction to the device, with more advanced operational features described in separate sections that are more or less independent, with cross-refences as needed. Each pair of facing pages complements each other, with illustrative graphics on the left and explanatory text on the right.

Built-in Tutorial. Included in the operator's manual and integrated into the device's firmware is a built-in tutorial providing a "hands-on" introduction to the basic operation of the device. Setting up the device to go through the tutorial requires only a few keystrokes described at the start of the manual. The firmware includes self-installing sample overlays (keyboard definitions) and vocabularies to use with the tutorial in the manual and to provide examples for further independent vocabulary development by the system operator or support person.

Vocabulary Packages. As part of the overall device support strategy, a variety of pre-defined overlay and vocabulary packages have been developed that are targeted at different age groups and cognitive levels, from pre-school through adult. These can be loaded into a device then further modified and set-up specifically for a given type or category of selection techniques. The modified versions can be saved on disk to provide an appropriate starting point for a given system operator with specific needs. Based on the operator's subsequent experience with the device, the set-up can then be fine-tuned over time to optimize the device's operational characteristics for that particular operator.

Menu-driven Operation. Menus are generally the preferred method of transaction control for new or casual users because they provide two major advantages. One is that they provide an obvious structure to the software and help the user to rapidly develop a model of how the system works as a whole. Another is that they rely on the ability to recognize information rather than having to recall it from memory [Dumas, 1988]. A further advantage of menus for an augmentative communication device is the fact that their operation can be designed together with the selection techniques implemented in the device to provide an interface that can be easily controlled as well as understood by the system operator. For example, an efficient scanning method can be automatically invoked for those using a scanning selection technique. Alternatively, the keyboard can be interpreted as pre-defined quadrants specifying menu selections to provide large target areas for direct selection techniques such as headpointing. Menus can also be scanned auditorially or read aloud for non-reading or visually impaired system operators. Menus are also particularly well suited for providing context-sensitive help information. All menu screens are constructed identically, with a title on the top display line, followed by up to four active choices (numbered 1 - 4), 5 to exit (back up the menu hierarchy), 6 and 7 to navigate horizontally through related menus at the same level of the hierarchy, 8 to read the menu aloud using the speech synthesizer, and 9 to obtain the context-sensitive help information explaining the choices available in the menu.

Function Macros. A common complaint of experienced users of strictly menu-driven interfaces is a lack of speed in controlling the application. This issue was addressed by providing the ability to encode any menu transaction (or combination of transactions) in a single function macro. A macro can be created to take the operator into any menu at any level and make choices from that menu when the macro is activated. Alternatively, the macro can be written to enter any menu and make pre-determined choices without requiring any interaction from the operator other than to activate the macro. Functions macros can be assigned to the device's overlay as the definition of the effect of a particular key activation, or encoded as part of the vocabulary stored in the device. Such macros allow the system operator to modify the operational characteristics of the device "on the fly" with as little as a single keystroke.

"System Toolbox." The device is designed such that the customized overlay for normal usage is mounted on a hinged keyguard that can be lifted to reveal an overlay to quickly access any of the system functions or menus and the complete character set. This is very convenient for the system support person, especially when trying to set up an overlay or vocabulary for a pre-literate system operator where most of the needed characters and functions would not be included in the custom overlay definition.

On-line Help. While not intended to replace printed documentation, an extensive, well-written on-line help system has become an accepted goal of many major software applications [Dumas, 1988]. With augmentative communication devices, there often seems to be a tendency to refer to a printed manual only as a last resort. The provision of well-designed, complete on-line documentation in a device would of course be helpful to an able-bodied support person, but more importantly, it would also enable the system operator to access this documentation. This then provides the system operator with the opportunity to explore new features of the device unassisted. The help function itself works as follows: the system operator activates the help function (either assigned to a key or encoded in the vocabulary), then activates the function or menu for which help information is desired. If this second activated function is also the help function, an extensive menu of help topics is brought to the screen from which a selection is then made. Once a help topic screen is displayed, it is possible to navigate backward and forward through multiple screens before exiting back to the original environment. As in the case of menus, the information on the help screens can also be read to the system operator using the device's speech synthesizer. Most help screens include a cross-reference to the the relevant section of the printed manual providing greater detail.

Context-sensitive Help. In addition to the help screens described above, there is also an extensive system of context-sensitive help available whenever making a selection from a menu or answering a question posed by the system. As described above, all menu screens are constructed identically, with help information available as selection 9 (or by activating the help function). The display screen is large enough so that sufficient explanation can be included with most yes/no questions, but in rare cases where more explanation might be helpful the help function can also be activated.

Review Vocabulary Utility. Managing a large vocabulary is a potentially time-consuming task with a number of different aspects. An obvious basic function is simply to know what words, phrases, sentences or function macros are stored in the vocabulary. Another function would be to report which encoding sequence or sequences either contain or exactly match a given text string. Also useful would be a way to report on the key assignments in the custom overlay and the utilization of elements in the encoding system. All of these functions were implemented in the Review Memory menu. The information generated can be displayed on the device's LCD screen, printed on the built-in printer, or sent out the serial port to a printer or computer.

Sequence Prediction. A large vocabulary containing thousands of items stored under various key sequences certainly requires a significant amount of exposure and study to become "fluent" in its use. Any guidance that can be provided in learning or recalling the encoding sequences for words is of potentially great benefit. An LED matrix on the front panel of the device is used to provide feedback regarding which keys are valid (non-empty successors) at each point in entering a sequence. Before beginning to enter a sequence, the LEDs light up at every key which occurs as the first key in at least one non-empty sequence. As subsequent keys are selected, the LEDs would be lit only at those locations corresponding to keys which are valid successors of the previously selected keys [Kushler, 1991].

Code Sequence Tutor. Even with a very large stored vocabulary there is of course a need to be able to spell words not in the vocabulary. However, when a system operator is still learning the encoding used for all of the various words, he or she may resort to spelling a word that is included in the vocabulary simply due to not yet remembering the encoding sequence used for that word. To help the system operator learn all of the encoding sequences used, the device can be set to automatically search the vocabulary data base each time a word is spelled, and report to the system operator if the word could have been generated from an encoding sequence, thus requiring significantly fewer keystrokes. If so, an informative message appears at the bottom of the screen, and optionally, the keyboard LEDs can be flashed in sequence showing directly where the encoding keys are located.

## EVALUATION

The device described in this paper began beta-testing in the summer of 1990, and was used by four system operators from that time through the present. During the same period it was used and evaluated by 40 speech language pathologists specializing in augmentative communication. The results of the beta-testing were highly encouraging, and much positive feedback was received regarding the device. Production and shipping of the device began in November of 1991, and again the feedback received from system operators and professionals in the field has been overwhelmingly positive. Plans are underway to implement an automated data logging system in the device to enable the collection of objective data for future evaluation.

## DISCUSSION

The speech therapist's time is a valuable resource, and anything that can be done to help make more efficient use of it will benefit both the therapist and the system operator. In any case, the amount of time that the system operator spends in direct contact with the therapist is generally quite limited compared to the time spent with the device itself (hopefully the device should always be available to the operator). By providing on-line support which is accessible at all times, the operator is enabled to independently further explore the potential of the device and to become more fluent in its use and familiar with the available vocabulary.

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Clifford A. Kushler, Ph.D.
Technical Director, Prentke Romich Co.
1022 Heyl Rd., Wooster, OH 44691

# DEVELOPING USEFUL USER DOCUMENTATION FOR AAC DEVICES: ONE COMPANY'S EXPERIENCE

Nancy A. Young
Prentke Romich Co., Wooster, Ohio

## ABSTRACT

As AAC devices become more complex, the documentation for them should become less complex and easier to understand. The primary responsibility of good documentation is to make learning how to use the product simple and to make finding out the things you want to know about the product easy. This paper will discuss how our company went about finding and adapting a style of documentation which would present a complex device to the public in a manner that would not frighten them off but would, in fact, allow them to feel comfortable and confident about learning to use the device. A short history of documentation and the evolution of documentation objectives at the company, a description of the documentation used for the new device and a discussion of the success of this documentation will be presented.

## BACKGROUND

In the early years of our company, the engineers wrote the manuals for the products they developed. Engineers are not known for their lucid creative writing. They *are* known for their desire to tell you more than you ever wanted to know about why the inside of something they made works the way it does. This made manuals interesting to other engineers but incomprehensible to the regular people who bought the product. We were as guilty as other high tech companies of being so focused on the technology itself that user-friendly documentation to go with the technology was considered as an afterthought when it was considered at all.

The eventual development of our early AAC devices brought documentation into focus for the company. We now had a product which could truly enhance and enrich people's lives but only if they could learn to use it on their own—and engineering spec sheets simply were not conducive to learning for most people. We knew that for a product which was the cornerstone of our company we could not just assign the job of writing the manual to anyone who could speak literately and who also had some free time; but that's about all we knew for sure. We had no idea what a good manual should be like. We explained our predicament to the people at Carnegie Mellon and asked for help. They pointed us in the right direction by writing the tutorial for our new device. We liked the idea of this tutorial—lots of explanatory graphics, text surrounded by a lot of white space and it was fairly easy to understand. The Hardware and Troubleshooting sections of the manual were completed in-house following Carnegie's guidelines.

We stayed with this format for about three years or until we developed another new AAC device. We wanted the manual for this new device to explain the device in such easy-to-understand terms that it would take very little training in the field for people to become competent with it. This time, Barry Rogers from the Trace Center worked with our newly hired manual writer to devise a somewhat different format for documenting this new product. Basically, the format consisted of a graphic on the left-hand page and text that supported the graphic on the right hand page. Even though the pages were numbered consecutively, in effect each even numbered page and its facing odd numbered page explained the same concept. One could read the title of the concept, a summary of the concept and a complete explanation of the concept on the "text page" or one could look at a graphic on the "graphics page" which explained pictorially the same concept addressed by the text.

At the same time we were marketing this product, we were working on developing a completely updated and in some ways revolutionary new communication device. This device, because of new technology and a dedicated hardware and software team, would by definition be technologically complex. The manual would *have* to be easy—both in concept and organization or prospective users would be scared away before they realized how simple the device was to operate. What had we learned from past manuals? What were our objectives for this manual? How could we best implement those objectives?

## OBJECTIVES

Over the years we had learned something interesting about the public's response to manuals. People seldom take time to offer feedback on a manual unless the manual is very good or very bad. The frustration caused from trying to wade through a bad manual causes most people to complain vociferously and, conversely, a manual that makes learning easy is such a surprise to most people that they will mention it in passing if they are calling or writing about something else. From this we saw that an effective way to gauge the success of a manual is by the amount of positive feedback we got *or* the fact that we heard nothing at all about the manual. No feedback at all meant we had written a manual that worked, was useful and didn't annoy people. If people took the time to call or write to us with positive comments about a manual, we knew we had a winner. We saw that with each major manual we produced, we had fewer complaints and eventually people began to comment positively on a specific manual. The positive feedback centered around the easy accessibility of the "one page, one concept" format. People seemed to believe they could handle one concept at a time, at their own pace, until they began to feel comfortable using the device. We decided to write the new manual using this one page, one concept format. We wanted people to be able to open the manual at any chapter and feel comfortable reading the information as well as confident that they could perform the task. We wanted the tutorial to be ABC basic, yet cover all the possibilities for quick, complete beginner's use of the device. We wanted the manual to read as if a regular person, not a computer or engineering wizard, had written it. We wanted the manual to reflect the power of the device but not to force the complexity on users until they were ready to advance toward it. We wanted the device and the manual to compliment each other.

## METHOD/APPROACH

One of the approaches our company took on its quest for good documentation was to hire a manual writer who came from a non-technical background. Instead of having complete technical knowledge of how a product works and then trying to distill that knowledge to the point where an ordinary person can understand it, the non-technical writer approaches a new product exactly the way a consumer does. The things the writer wants to know turn out to be, more often than not, exactly the same things the consumer wants to know—How do I turn this on? How do I make it speak? How do I store vocabulary or make it print or push the buttons without breaking it? And in learning how to use the product, the non-technical writer moves from the basics into feeling comfortable with the device and then into curiosity about advanced applications and functions. It's almost impossible for the non-technical writer to fog up the tutorial with references to the amazing advanced functions of the device because the writer doesn't yet know what the advanced functions are. A good writer who is discovering how to use a new product will write the discovery and learning process as it is being experienced in simple conversational prose.

The next approach we settled on was to use the one page, one concept idea. Believing that a potentially intricate device needs a manual that is easy to understand, we decided to divide the manual into a number of sections each of which would be concerned with an aspect of the new device, e.g., tutorial, advanced functions, language, etc. Each section would be divided into chapters and each chapter would be divided into any number of facing-paged, self-contained documents. The left- hand page would always contain graphics for the single concept and the right-hand page would always contain the text for the concept. The manual would begin with the tutorial which would teach users the groundwork needed to be able to use the device in its most basic configurations. Each section after the tutorial was considered as a building block which could be added to the information gained from the tutorial. Consumers could choose the chapters and concepts they wanted to know about and be

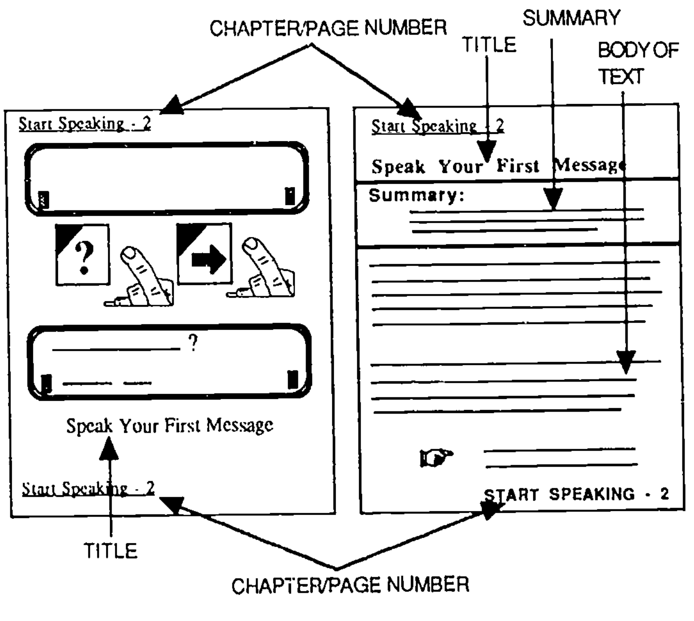


Figure 1. Sample page from the manual

cause each chapter consisted of facing-paged documents which explained a single concept, it was never necessary to read an entire section in order to understand a chapter. In fact, it was rarely necessary to read a whole chapter in order to understand one of the concepts.

Finally, we decided to color code sections and chapters for easy reference, to downsize the manual from 8 1/2 x 11 to 8 1/2 x 6 and to bind it in a sturdy three-ring binder. We also added a stand-alone Quick Reference Guide which contained only the 1-2-3 step directions for performing various tasks on the device.

Once the conceptualization and organization of the manual were finalized, what remained was the writing. The one page, one concept format created a tangible boundary within which the writer had to write. This forced the writing to be clear and simple. If a concept took more than one page to explain, the writer was probably unclear about the concept. Either the task needed to be relearned or the concept needed to be broken down into more manageable parts and rewritten. The writer always approached the device, the concept and the task of explaining them from the user's point of view. And, in fact, the writer with a non-technical background *is* a neophyte user. What the writer discovers, understands and then explains is exactly what a user will be able to discover and understand through reading. If life is fair, this process of learning and writing about what was learned *as a user* will produce a manual that will be regarded as an important and often-used resource for the consumer.

## RESULTS/DISCUSSION

By the time the device was ready to be beta tested, the manual had grown so thick that our fear was no longer that people wouldn't understand the manual, but that they wouldn't even open it because of its size. Both the device and the manual were given to users of our other AAC devices, to speech and language pathologists, to authors of program applications for other devices and to people in-house who had not worked on this particular project. With all the beta testers we stressed the necessity of using the tutorial in the manual to become acquainted with the new device but we did not pressure them to use the manual beyond this initial stage. Surveys were sent out periodically asking the testers to evaluate certain areas of concern; among these were questions concerning the manual. Without fail, this diverse group of people responded by praising the manual, citing how easy it was to understand, how well organized and how non-intimidating it was despite the size. All were surprised by how easy the device itself was to use and how well the manual facilitated learning. There were suggestions for clarity and improvement, but there were no pleas for a different format or simpler writing. All of the beta testers learned the rudiments of the new device from the tutorial of the manual and most of them went on to teach themselves many more advanced functions by simply leafing through the manual to find those pages whose concepts appealed to them. Our Education and Training Department developed training classes for this device using the manual as the textbook because it was so easy for participants to understand.

The new device has been on sale for 8 months and the feedback we are receiving on the manual is still overwhelmingly positive. The one page, one concept format for documentation may not be feasible for all product manuals, but we have found it to be the best possible format for explaining our AAC devices, where an incredible amount of information must be disseminated so that many different kinds of people can understand and benefit from it.

One of the things this experience has taught us is that when it comes to explaining highly technical devices to the general public you can almost never be too simplistic. This does not mean talking down to the consumer. It means respecting the intelligence of consumers enough to make learning the basics of a sophisticated device so easy that they are eager and confident to discover new ways of using the device on their own. The structured format we used for this manual and the non-technical approach we brought to writing it, seems to facilitate the consumer's acquisition of both knowledge about the device and the self-confidence to continue to learn.

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Nancy A. Young
Technical Writer—Operator Manuals
Prentke Romich Company
1022 Heyl Rd.
Wooster, Ohio 44691

# Towards Modular AAC Software: An Object-Oriented Architecture

Patrick Demasco, J. Eugene Ball, Steinar Tyvand, Denis Blodgett, William Bradley, John Dunaway, Zunaid Kazi
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware Wilmington, Delaware USA

## Abstract

In this paper, we discuss progress that is underway in the development of a software architecture for Augmentative and Alternative Communication Systems. The practical results of such an architecture will be a common framework that will allow developers to collaborate in systems development and a toolkit that will allow rapid development of new and unique systems. This paper focuses on an overview of the class library which we call LASO. It presents it in terms of a class hierarchy and example configuration that illustrates class connections.

## Introduction

The design and implementation of AAC system software continues to be a major component of the development process. While the availability of toolkits and programming environments for other specialized application areas such as databases have become commonplace, it is still the fact that AAC developers program systems from scratch. In a previous paper (Demasco et. al., 1989) we proposed the development of a software architecture that would provide a specification of software modules and their interfaces. For this architecture to be useful it must meet the following criteria:

flexibility - The architecture must provide the flexibility to implement a diverse range of capabilities.

extensibility - It should provide a path to easily incorporate new strategies that are not directly supported.

minimal coupling - The developer using the architecture should be free to use those components that are most useful and not be required to adopt the entire system.

efficiency - The software should be efficient enough to run adequately on a broad range of hardware platforms.

portability - Hardware dependencies should be well isolated so that the architecture (or even parts of it) can be implemented on a variety of platforms. This includes personal computer-based systems and dedicated hardware.

The practical outcome of such an architecture are two-fold. First, we believe that it will be possible to release a developer's toolkit that will provide many necessary and common functions for system software and will furthermore free system developers to work on more innovative parts of their software. Second, the availability of a specification for software modules and interfaces provides the opportunity for researchers and developers to share code. While we realize some of the practical problems with corporate developers sharing code, we think that there can be a tremendous benefit among academic researchers.

## Background

Our work within this project has been to develop an architecture specification, implement a prototype of the architecture in C++, and to produce and maintain a developer's kit that will contain our own code modules and (eventually) other people's contributions. In more recent work, we have segmented the architecture into two distinct components. LASO (Library of Adaptable Software Objects) is a collection of C++ classes that implement the majority of the architecture specification (Demasco et al., 1990). *Adapt* is an interpretive authoring language based on LOGO (Ball et. al., 1990). It provides the capability to attach scripts to key selections, and to provide a dynamic description of the system in terms of the specific LASO module that are needed and their inter-connections. It is useful to distinguish between these two components, because LASO provides the tools for a developer to create a system while Adapt is designed to provide authoring capabilities to the end-user (e.g., clinician, rehabilitation engineer, consumer).

A very similar project has been underway since 1989 by a consortium of European researchers known as the Comspec group. They also seek to develop a common specification for software modules that can be shared among the development community. In a technical report (Comspec, 1990), the group outlined the rationale, requirements, and a proposed structure for a software library. More recently, (Svanræs, 1991) they have developed a Smalltalk based prototype that demonstrates their approach.

In this paper, we would like to discuss progress made in the development of our architectural specification. In particular, since we only have presented descriptions of specific components of the architecture previously, we would like to take this opportunity present the entire architecture as a whole. The greatest overall change in the architecture has been an attempt to achieve greater compatibility with the structure developed with the Comspec project. In particular, we have adopted (and expanded upon) their Navigation Protocol which defines a set of messages between the input and processing sides of a system. The effort towards compatibility is largely possible because all parties concerned have embraced an object oriented methodology which allows us to approach the problem in a similar way.

## Approach

In our work, we have taken a bottom-up and incremental design approach. By bottom-up, we mean that we generally start by looking at "low-level" object functionality and working up towards more complex structures. For example, we started the vocabulary set class by first designing a vocabulary *item*, then a vocabulary *group*, then a vocabulary *page* and then a vocabulary *set*. By an incremental design approach, we mean that we have implemented components during the design process to test the validity of the concepts.

Figure 1. shows a class hierarchy for the major components of LASO. We originally avoided the use of a single hierarchy and preferred a collection of separate class hierarchies. This was largely because 1) We did not have a good reason to link all of the classes together; and 2) We wanted to minimize the coupling between different class hierarchies. Since then we have moved to a single class hierarchy largely to support operations that dynamically configure the system (this is discussed later in the paper). All of the major classes in the system are descendants of the *LASO-Object* class. While this does create a connective relationship between all of the important system modules, it does not necessarily create an undesirable coupling effect. It only requires a developer to use *LASO-Object* with any subset of the

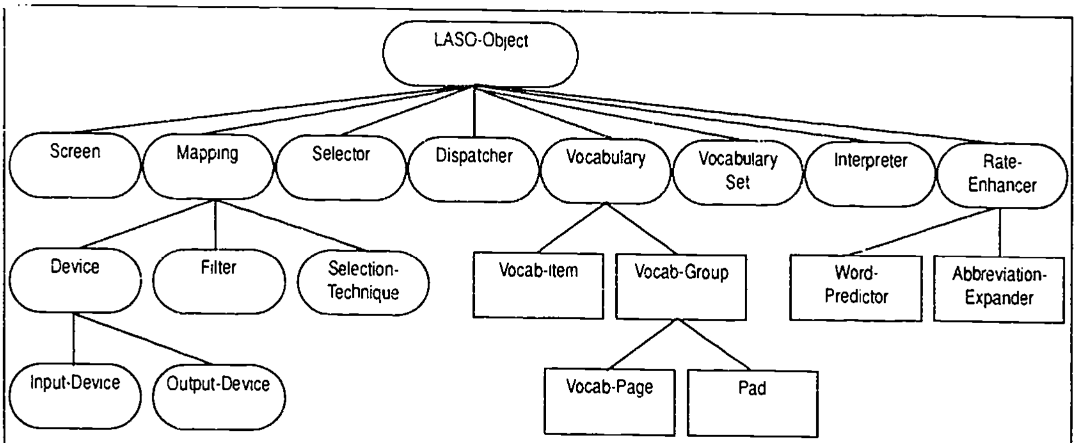


Figure 1. LASO Class Hierarchy. Abstract classes shown with rounded rectangles.

modules shown. Each of the major modules are briefly defined below:

Screen - The *Screen* class defines a portable interface to the host systems graphics hardware and/or windowing system.

Mapping - This class maps some type of input event into some type of output event. It includes *Input-Device* and *Output-Device* classes which have derived classes that implement specific devices[1]. It also includes *Filter* classes that are used primarily to filter input device signals. Finally it includes a *Selection-Technique* class. Different selection techniques (e.g., scanning, direct selection) would be implemented as classes derived from Selection-Technique.

Vocab - The *Vocabulary* class defines a data and function for a very general list structured vocabulary set. It defines a vocabulary item (*Vocab-Item*), group (*Vocab-Group*) and page (*Vocab-Page*). In addition, since one of our system requirements is that editing buffers be accessible in the same way as vocabulary pages, we represent editing buffers in the *Vocabulary* class. We define this as a *Pad* and specify that it behave as both an editing program and as a Vocabulary Page.

Vocabulary-Set - This class defines a collection of vocabulary pages.

Selector - This class serves as a major connection point between input (primarily through the selection technique), the vocabulary set, and output (primarily via the dispatcher). It is also responsible for basic display management functions such as deciding where to put the *Vocab-Page* and the *Pad*.

Dispatcher - The *Dispatcher* is responsible for processing actions that are the result of the selection of a vocabulary item. It may send the item to the *Pad* or (if it has a script attached) to the *Interpreter*.

Rate Enhancer - This class consists of rate enhancement functions such as word prediction and abbreviation expansion.

1. In fact this is common throughout the class hierarchy. Any "leaves" on the tree that are abstract means that specific classes will be derived from that class. For example, *Input-Device* defines an interface for input devices, but specific devices (e.g., joystick, mouse) will be implemented as derived classes.

Interpreter - This class is responsible for executing scripts that are typically attached to vocabulary items.

This hierarchy defines an overall structure that takes advantage of the Object Oriented feature of inheritance. Each derived class inherits from its parent's data and methods. When implemented in C++, it allows us to "plug-in" different modules and have the system behave correctly. For example, since the class *Selection-Technique* defines a common set of methods for its children we can replace a single switch automatic scanning class with a single switch step scanning class without affecting other parts of the system.

### *Class Connections*

In order to illustrate how the LASO classes are used it is easiest to present an example configuration. A class connection diagram provides a good view of the relationship between classes and is shown in Figure 2. This diagram assumes an event driven model where input device signals will trigger events in the *Input-Device* class, and this will drive the system. In this example, we are assuming automatic single switch scanning that is activated by pressing the left mouse button.

Input - When the user presses the left mouse button, the *Mouse* class (which is a child of the *Input-Device* class) will send a message to the *Single-Button-Filter* class (which is a child of the *Filter* class) notifying it that the mouse is pressed down. The filter activates a timer for a specified dwell time. If the timer expires before the filter is told that the mouse button is released, then it sends notification to the scanning technique. The *Single-Switch-Scanner* class (which is a child of the *Selection-Technique* class) on notification of a button press translates this into an *In* message that is sent to the *Selector*. The scanner also activates a timer that corresponds to the scanning rate. If the time expires before a mouse press message is received then it sends a *Next* message to the *Selector*.

Processing - The *Selector* receives "Navigation" messages from the selection technique. In this example of scanning it receives a *Next* message if the scan rate timer elapses and an *In* message if the user presses the switch. In the first case, the *Selector* passes the *Next* message on to the *Vocab-Page* and then asks it to highlight itself (if the operation was successful). In the second case, the *Selector* asks the *Vocab-Page* if the current focus is an item

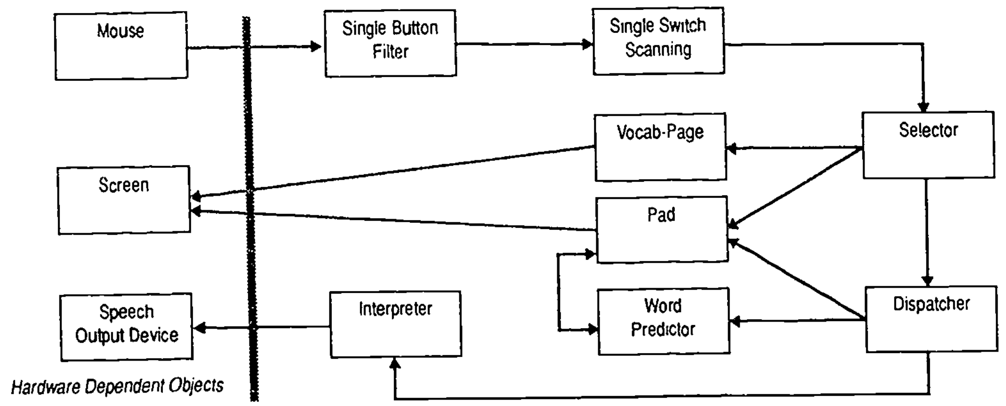


Figure 2. Example LASO Class Connections. Only major connections are shown for clarity (e.g., the Interpreter maintains connections to many of the objects in the system)

or a group. If it is a group, then it passes the *In* message to the *Vocab-Page* and then a *Highlight* message. If it is an item, then it requests that item and passes it on to the *Dispatcher*, whose job it is to perform actions appropriate for that item. In this example, the default action is to send the item's representation to the *Pad*. If there is a script associated with an item, then it is passed on to the *Interpreter*. These includes output operations such as "Speak Message" as well as editing commands such as "Delete-Word".

Rate Enhancement - In this example, we are showing word prediction (which architecturally, is more difficult to model than abbreviation expansion). There are two major functions that exist within word prediction: prediction and acceptance. Prediction occurs when an item is selected and it is added to the *Pad*. At that point the *Pad* notifies the *Word-Predictor* that an insertion has occurred (and what was inserted). The predictor updates its list of predictions and notifies the *Vocab-Page* of the new list. The page which has special slots to be filled with predictions will then update the display. When a user selects from predicted items, the *Dispatcher* recognizes that the item is a predicted item and rather then sending the item to the *Pad* sends it to the *Predictor* which replaces the word prefix with the word (via a message to the *Pad*).

The architecture as described provides the tools necessary to build a complete communication system in C++. We have also included a mechanism to dynamically construct systems at run-time. The *LASO-Object* class defines methods for reading a file-based description of the system objects and their connections. Data specific to each class includes parameters needed to instantiate the object and a description of the connection points. The process for dynamically building a system is to first declare all of the system objects and then define the connections between them. This process can also be accomplished through a start-up script written in Adapt.

## Discussion

We feel that the architecture as described provides a means to develop a wide range of systems on a variety of hardware platforms. The use of object-oriented programming provides a great deal of flexibility through polymorphism. In addition, it supports extensibility through the mechanism of inheritance.

We are currently using LASO in-house to develop a communication system called *Graphcom* that supports photographic quality images on a VGA display. We hope to release a preliminary version of the toolkit for use by other developers. This step will provide invaluable feedback as our work continues. Finally, we will continue to work with the Comspec group to insure as much compatibility with their work as is possible.

## Acknowledgment

Funding for this research was provided by a Rehabilitation Engineering Center, Grant Number H133E 80015 from the National Institute on Disability Research, U.S. Department of Education. Additional Support has been provided by the Nemours Foundation.

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Svanæs, D. (personal communication, May 30, 1991)

Patrick Demasco
Applied Science and Engineering Laboratories
University of Delaware/A.I. duPont Institute
PO Box 269
Wilmington, DE 19899
email: demasco@udel.edu

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# Photographic Quality Images in a Computerized AAC System

Lorie J. Miller, Patrick Demasco, Beth A. Mineo, & Dan Gilliam
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

## Abstract

Advances in computer technology have added power and flexibility to many augmentative communication systems. Still, users who rely on graphical representation of vocabulary sets have not been able to enjoy the same advances as text based users. New systems can only use abstract symbol sets that are inadequate for many users. To overcome this limitation, a new AAC system, named Graphcom, has been developed. Graphcom uses photographic quality, gray-scale images to display the contents of the vocabulary set. This allows the set to be individualized in a way similar to overlay systems, while taking advantage of the dynamic displays and speech output common in computerized systems. New images can be incorporated at any time making the system very responsive to the user. Speech output can be added to each image or to combined messages for the purpose of language training or functional communication.

## Background

Often an augme.itative communication system serves a dual purpo.e; that is, in addition to serving as a means of e<pression, it also serves as a springboard for languε.ge acquisition. For individuals whose symbolization capabilities are not fully developed, it is important that the language representations used on systems are as understandable as possible. Not too long ago, most computer-based augmentative communication systems had static displays of symbols. The benefit to such displays was that they could often be customized to include whatever type of symbols the user needed. These could be the alphabet, line drawings, photcgraphs, and ever in some cases actual objects. The drawback to these static displays is that they offered a relatively limited vocabulary set, and any expansion of the vocabulary required a collection of multiple overlays that had to be maneuvered in some way onto the display. The fairly recent introduction of dynamic display devices has solved the problem of having to physically "swap" overlays, because all overlays are accessed within the system. The new problem, however, is that the new systems are not capable of displaying all representational types. Typically, the language representations on commercially-available systems are limited to black-and-white line drawings. Furthermore, a generic representation is intended to symbolize a wide variety of real-world exemplars. For example, the line drawing of a glass could be used to represent ; *'ass*, *drink*, *juice*, *milk*, *thirsty*, or any number of other related concepts. The problem inherent in this approach is that for many individuals, the potential of the generic representation for a variety of meanings is nonexistent because the individual does not even recognize the line drawing of *glass* as a glass. This individual's concept of "glass" may be limited to the Flintstone glass that her/his caregivers routinely use for beverages. Thus, it would be much more meaningful to be able to represent her/his concept of "glass" within the system. A system capable of importing photographic-quality images would permit such representations. Of course, to provide a two-dimensional representation highly similar to the actual object requires that the system be able to duplicate the size and color of the object as well as to preserve the essence of the object by providing photographic-quality images.

## Rationale

Graphics capabilities on personal computers has advanced significantly since the introduction of the Apple II and IBM Personal Computers. When IBM introduced its PS/2 line of systems, it established a new graphics standard called VGA (Video Graphics Array). Along with improvements in high resolution modes (640x480 by 16 colors), the VGA standard provides a new mode that is suitable for photographic quality images (Wilton, 1987). This mode supports 256 colors (out of a palette of 262,144 colors) at a resolution of 320 by 200 pixels. In addition, the VGA adapter can be programmed to dispiay 64 shades of gray (at the same resolution).With the VGA, it is no longer necessary to limit symbol display to simple "black and white" representations. It is the goal of this project to take advantage of this new capability and provide a computer-based AAC system that can utilize gray-scale photographic quality images.

While VGA adapters can display color images with considerable quality, we have chosen to work with gray-scale images for the following reasons:

1. When using VGA in 256 color mode, photographic images that are captured typically specify a palette that optimizes the display for the qualities of the image. While this can yield good results with a single image, there is

significant degradation in image quality when multiple images (with different palettes) are view simultaneously.

2. Monochrome image capture peripherals for PCs are relatively inexpensive.

3. Color displays are not yet widely available on laptop computers. Those systems that support color are expensive.

The system we will describe provides the following capabilities:

1. The ability to capture gray scale images inexpensively on a desktop PC

2. The ability to record speech for each of the images.

3. The construction of multi-level vocabulary sets that use these images and speech segments.

4. An AAC system that presents images to the user; allows direct selection of these images; provides simple editing functions and speech output.

We hope that we have achieved these goals on a hardware platform that can be assembled at a reasonable cost.

## Design

This project began as a student design project in a rehabilitation technology oriented computer science course. While it provided all of the capabilities mentioned above, its design limited future extensibility. We have decided to redesign and implement the system in C++ which through its support for object-oriented programming promotes the development of more flexible and extensible code.

Rather than design the system from "scratch", we are using a preliminary version of LASO (Library of Adaptable Software Objects) which is an AAC developer's toolkit (Demasco et. al., 1990). LASO contains a hierarchy of C++ classes that defines functional elements of a software-based communication system. It also provides a set of interfaces or "messages" that define how the objects are connected. While a complete description of the library is beyond the scope of this paper, we would like to discuss those classes that were developed specifically within this project.

*Screen Class* - The Screen Class defines a device independent interface to the underlying graphics hardware. LASO currently provides Screen classes for X-Windows and Microsoft Windows. For this project we developed a Screen class for DOS-based VGA adapters using the Meta-Windows graphics library.

*Device Class* - LASO assumes an event driven model of input. To support mouse input in a DOS environment, we had to write a specialized Input Device Class that is triggered off of the DOS timer.

*Speech Output Class* - To support the Covox speech board, we needed to develop a LASO based interface to the Covox library.

*Interpreter* - LASO provides the Adapt script interpreter which is based on the LOGO language. For this project we needed relatively simple command processing. To conserve memory we developed a simple command processor that handles page changes, output commands and other functions.

*Selector & Dispatcher* - Within LASO, the Selector class handles basic display layout and processing of input messages. The Dispatcher processes items that have been selected. Simple variants on the LASO supplied class were developed.

It should be noted that most of these new classes will be added to LASO and become reusable components themselves. It is also important to understand that a significant portion of Graphcom's code has been taken directly from LASO. This includes selection techniques, image support (images are stored in the TIFF format) and vocabulary management.

## Development

The software is written in the C++ programming language and runs on any IBM compatible with a VGA adapter. It supports a wide range of VGA and Super VGA cards including 640x480x256. Screen layouts are displayed using the MetaWindows graphics library.

The system displays one screenful of pictures at a time, arranged in rows and columns. (Fig. 1) A vocabulary set may contain several of these arrangements, called "pages". When using the system, the user moves between pages using the "NEXT": and "PREV" boxes on the screen. As pictures are chosen, they are placed in the work area at the bottom of the screen. By clicking the mouse in any area of this workspace, the entire message is spoken.

All vocabulary and menu items are accessed via direct selection using a mouse. Mouse emulator systems can also be used such as the Headmaster or any touchscreen that provides mouse emulation. Each picture can have speech output associated with it that can be used independently or concatenated with other selections. Speech output is accomplished using the Covox Voice Master Key. This system consists of either plug-in boards or external boxes that can be attached to the printer port on a laptop computer.

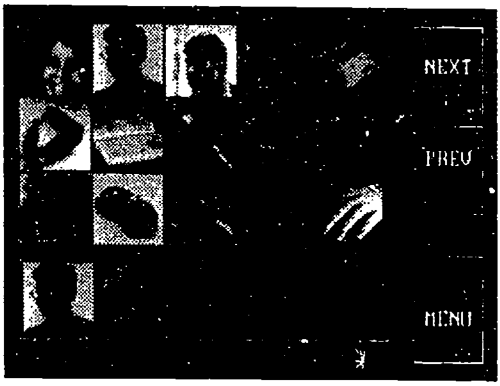


Fig. 1: Example of Graphcom Screen

The "Menu" option on the screen provides access to other features of the program. One of the primary features is the ability to add new pictures to the vocabulary set. New images are captured using an inexpensive camera (Electrim Corp. EDC-1000 Computer Camera) attached to the computer. After the image is captured, the user simply indicates where in the vocabulary set the new image should be displayed and the image is automatically inserted. New images can be captured and inserted at any time giving great flexibility to the content of the vocabulary set.

## Discussion

Graphcom is designed to utilize the best features of other types of communication systems. It uses the concept of the individualized overlay systems by incorporating life-like images that have meaning to each specific user. At the same time, it uses computer technology for flexibility, speed, and dynamic displays. The growing laptop market, with its parallel improvements in video technology, has allowed a system such as Graphcom to become a reality.

Graphcom could be used in a variety of applications. First, it could be used as an individual user's augmentative communication system. Second, it could be used as a training aid both for language acquisition and communication aid use. Finally, it could be used for evaluation to examine training progress or determine appropriate interventions.

With improvements in portable computer and laptop technology, improvements in Graphcom will be explored as well. Efforts will continue to provide the best quality images possible. In addition, the ability to scan images or currently used symbols will be added. This will provide maximum flexibility to the vocabulary set and allow transitions from images with which the user is already familiar. Other future improvements would be the incorporation of color and/or animation. Both of these changes would expand the appropriate client population and possibly improve functional use in those clients already using the system.

It is hoped that Graphcom will be transferred out of the laboratory in its current version in the near future. Work in continuing on its basic features and an initial system, using gray-scale images with speech output, should be ready for transfer soon. Our goal is to make the system available to the consumer in its current form and upgrade the product as technological advances allow.

## Acknowledgment

Funding for this research was provided by a Rehabilitation Engineering Center, Grant Number H133E 80015 from the National Institute on Disability Research, U.S. Department of Education. Additional Support has been provided by the Nemours Foundation.

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Lorie J. Miller
Applied Science and Engineering Laboratories
University of Delaware/A.I. duPont Institute
P.O. Box 269
Wilmington, DE 19899

# The Development of a Child's Voice for use in Communication Devices

**Debra Yarrington, Othman Mohamed, & Richard Foulds**
Applied Scince and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

**Abstract**

This paper describes the development of a synthesized child's voice. The voice has been synthesized using a library of diphones stored in the time domain. By using diphones stored in the time domain, the system has created a voice that is very realistically childlike and also allows for an unlimited vocabulary.

**Background:**

Diphones are segments of speech that extend from the steady state of one phoneme through the phoneme transition to the steady state of the next phoneme. A steady state of a phoneme is considered the state at which the formants, or peak resonant frequencies, remain consistent. By having diphones begin and end at steady states, they should append together smoothly. [1] Hence there should be no need for complex algorithms to model the transitions that a phoneme-based synthesizer would need. Since there are a limited number of phonemes in American English (and any language), only a limited number of phoneme transitions exist. Therefore, a complete diphone inventory would require a limited amount of memory, yet allow for an unlimited vocabulary. [2]

For this synthesizer, the diphone segments were stored in the time domain. Storing the diphones in the time domain means that the waveforms were recorded and digitized with very little manipulation other than filtering. In this way almost all of the original information in the waveform is retained. Therefore all the information that makes a voice unique would be retained in the stored waveform.

**Statement of the Problem:**

The goal of the authors was to create a synthesized child's voice that was realistic, highly intelligible and unlimited in vocabulary, yet had limited memory requirements for use in communication devices. To date,little research has been done with children's voices. This is largely due to the higher frequencies in children's voices than in adult female and especially adult male voices. The relationship between formant values in children's voices is also different than in adult voices. Hence a lot of the research being done with male voice synthesis has limited application to the creation of children's synthesized voices. Yet there is a most definite need for children's voices in communication devices. Many such devices are used in school systems, and it is inappropriate for a 6-year-old girl with limited vocal abilities to be communicating with a 40-year-old male voice. The authors felt there was a strong need for a high quality child's synthesized voice.

**Design:**

The design of the child's voice consists of 3 parts: The creation of a library of diphones; the development of a system for converting orthographic text into its phonemic counterpart; and a method for appending the diphones together to create synthesized speech.

**Development and Rationale:**

*The creation of a library of diphones:*
The creation of a library is a tedious and time consuming process. First, an inventory of all possible phoneme transitions necessary for an unlimited vocabulary was developed. Originally, only diphones were going to be used for the inventory. However, certain sounds are highly influenced by their surrounding sounds and have no consistent steady state. To improve the quality of synthesized speech that uses these sounds, it was decided that these sounds should be included in the inventory as polyphones. These sounds were also included in the inventory as diphones as a backup in order to maintain the unlimited potential of the voice.

After the inventory of diphones and polyphones was developed, a list of carrier words containing all those diphones and polyphones was generated. A 7 year old girl with normal speaking abilities was selected as the voice prototype and recorded saying each word twice onto digital-audio cassettes in a sound booth. The recordings were filtered using a bandpass filter with cutoffs of 8kHz and 100Hz. The recorded words were then digitized using a sampling frequency of 20.2k. The large bandpass and high sampling rate were chosen because of the higher frequencies in a child's voice, and also because it allows some room for waveform manipulation without any detectible loss of quality in its sound.

Once the carrier words were digitized, their corresponding diphones or polyphones were manually extracted, labelled, and stored as time-domain waveforms in the diphone inventory. The library was stored on a Sparc workstation and extracted using EDW, which is public domain waveform editing software written by Dr. H. T. Bunnell. The diphones and polyphones were extracted using a set of rules that were based on the type of sound being cut. For instance, because coarticulation effects are more likely to affect previous sounds than following sounds, vowel sounds were extracted at the very beginning of their steady states. Some of the extraction rules also allowed us to control simple prosodic components of speech. For instance, certain extraction rules allowed us to compensate for the longer duration of most phoneme sounds at the ends of words.

*The development of a text-to-phoneme system:*

The central focus of our text-to-phoneme system is a large list of words and their associated phonemic representations stored in a dictionary file. A set of rules for converting text into its phonemic representation was also included as a backup to the dictionary. The choice of including a large phonemic dictionary rather than develop a complex and comprehensive set of conversion rules was made for a number of reasons. The first and most obvious is accuracy. Each word stored in the dictionary will obviously have the correct pronunciation because it is stored with the correct pronunciation. Storing the phonemic representations of words also allows the storage of some simple stress information about multisyllabic words. In this way, the correct syllables are stressed and deemphasized, greatly increasing the intelligibility of the multisyllabic words. The large size needed for a somewhat comprehensive dictionary is much less of an issue than it was in the past because memory has become cheaper and more compact over time. There is no indication that this trend will reverse itself. As a result, the necessity for creating a comprehensive set of rules for converting text to phonemes seems less important. The final rationale for choosing to emphasize the dictionary rather than the rules was efficiency. The English language is filled with exceptions to the rules for proper pronunciation. It is almost impossible to develop a system for converting text to phonemes without a dictionary of words that do not follow the rules unless the rules become so comprehensive that they included one rule for each word that does not follow the rules. However, most systems (including ours) do include an exception dictionary along with the rules. Since the exception dictionary is searched first, and the rules second, the system would be faster if all of the most commonly used words in English were included in the exception dictionary. In this way, frequently used words are converted to phonemes quickly rather than first searched for in the exception dictionary, and then broken down by the rules each time they are used.

Although the previous arguments would suggest that conversion rules were becoming almost superfluous, they are still necessary if the system is going to accomodate an unlimited vocabulary. So this system included a back-up set of rules. These rules are based on rules developed by the Naval Research Laboratory in Washington, D.C.

*Development of a method for appending diphones:*

In theory diphones should append together smoothly with no manipulations necessary. Since both the beginning and ending of the diphone should be at steady states of their phonemes, and since the formant values in a phoneme should be consistent for each speaker, matching diphones at phoneme steady states should lead to natural sounding transitions. Unfortunately, phonemes in speech are not this consistent. The most obvious reasons for this are pitch differences. If the pitch of one diphone is different from the pitch of the diphone to which it is being appended, the resulting speech will have an unnatural sounding click in it. Another reason diphones do not always match up smoothly is because of coarticulation effects. If one phoneme is influenced by one set of sounds, and another phoneme is influenced by another set of sounds, their formant values will be slightly misaligned when they are appended together. If the misalignment is great enough, the resulting speech will again sound unnatural. Diphones also may not append smoothly because of amplitude differences. As a result, it was necessary to develop a method for smoothing the diphone boundaries. Since the diphones were stored and played back in the time domain, the smoothing had to be in the time domain as well.

The first and easist step taken to help smooth the diphone boundaries was to adjust the amplitudes. The amplitudes were all adjusted to an average of 67db using a multiplication factor.

The next step was to smooth the pitch differences. This was accomplished by first locating one pitch period at the ends of the diphones being appended. The average pitch of these two pitch periods was then determined, and each pitch period was progressively time warped to the average pitch. These adjusted pitch periods were then appended in between the two diphones, creating a smooth pitch ramping between the two diphones.

**Discussion:**

The synthesized speech resulting from this system is very high quality, natural sounding, and intelligible. It is very obviously a child's voice, and even identifiable as the child whose voice was recorded.

This system bypasses many of the problems associated with the development of a child's voice by incorporating frequencies up to 8kHz and by doing almost no analysis to the diphones. The wide bandwidth more than allows for the higher frequencies in a child's voice. By storing the diphones in the time domain, there was no need to worry about formant relations particular to a child's voice.

Certain aspects of the system need to be developed further. In order to create a child's voice, it was necessary to record a child. Children are less likely to enunciate clearly than adults. Children are also less able to maintain a consistent pitch. It would be desirable to have a child sit up straight and still at a uniform distance from the microphone when recording. Children do not sit straight, still, or uniformly for very long. As a result, recordings can have very different pitches, amplitudes, and frequencies in them. Therefore the method for smoothing between diphones cut from these recordings must be much more robust. The current system does compensate for amplitude and pitch differences. However, it does not adjust the overall pitch and amplitude pattern of the synthesized speech, and does very little to compensate for unmatched formant values caused by poor enunciation and coarticulation effects. So the pitch, amplitude, and formant values can change at each diphone boundary. The resulting speech could have very unnatural frequency and amplitude contours.

A similar issue is the prosodic information contained in the synthesized utterance. The current system incorporates very little prosody. Work should be done on imposing pitch, amplitude, and duration changes into the synthesized speech at syllable, word, and even phrase boundaries.

**Acknowledgement**

Funding for this research was provided by The Rehabilitation Engineering Center, Grant Number H133E80015, from the National Institute on Disability and Rehabilitation Research, U.S. Department of Education.

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[2] Boubekker, M., Foulds, R., Norman, C. "Human Quality of Synthetic Speech Based Upon Concatenated Diphones", Proceedings of the Ninth Annual Conference on Rehabilitation Engineering, Minneapolis: 1986

Debra Yarrington
Applied Science and Engineering Laboratories
Alfred I. duPont Institute
P.O. Box 269
Wilmington, DE 19899

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# Parlante: A Spanish Text-to-Speech System with Automatic Pitch Contour Assignment

**Pamela Trittin, M.S.**
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

## ABSTRACT

Parlante, which means *one who speaks* in Spanish, is a system designed to convert Spanish orthographic text to intelligible Spanish speech. Parlante can be incorporated into a communication device so that individuals with severe speech impairments can converse in a Spanish-speaking community. One of the essential components of a text-to-speech system is intonation assignment. The focus of this paper is to provide an understanding of a system which automatically assigns pitch contours to synthesized Spanish speech.

## BACKGROUND

A very useful tool for human/computer interaction is speech synthesis. Technology has made it possible to produce synthesized voices which can be used in telecommunications, user interfaces, as well as devices for disabled individuals (especially those who are speech and visually impaired). Synthesized speech can be obtained by implementing a text-to-speech algorithm. Systems which follow this approach have been around for some time now. Among them are MITalk [1], Spanish text-to-speech system [5] and an English system explained in [11]. The system described in this paper, Parlante, also uses a rule-based algorithm to translate the orthographic input into an acoustic signal following the letter-to-sound rules of the Spanish language.

## STATEMENT OF THE PROBLEM

The problem with many systems is that the resultant synthesized speech is unnatural. Oftentimes prosodic features of speech utterances are not considered. These features are important because they affect expressions as a whole instead of independent segments. Without prosody, speech is very monotonous, and it lacks rhythm. Among the prosodic features are intensity, rhythm and intonation. At this stage of development, intonation is the only prosodic feature incorporated into Parlante.

## RATIONALE

As the number of Spanish speakers in the United States continues to grow in number, so does the need for Spanish speech synthesis devices. Since information pertaining to Spanish speech synthesis is scarce and very difficult to obtain, further investigation in this area is necessary.

## DESIGN

Parlante's general architecture is illustrated in **Figure 1**. The three main phases of the system include text-to-phoneme translation, intonation assignment and speech synthesis.

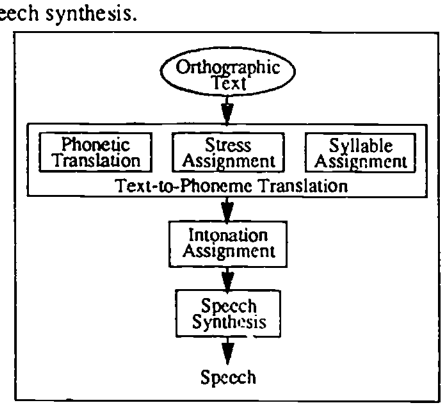


**Figure 1: Parlante's General Architecture**

The text-to-phoneme module converts the orthographic text into its phonetic translation using letter-to-sound rules of the Spanish language. These rules are based on those described in [3]. After obtaining the phonetic representation, stress and syllable markings are applied to the phonetic representation. This first phase--text-to-phoneme translation--is discussed thoroughly in [6, 8]. The next procedure assigns a pitch contour to each word, phrase or sentence entered into the system. Finally a cascade formant synthesizer takes a set of parameters influenced by rules governed by the prosodic features and produces speech output.

### *Automatic Intonation Assignment*

Intonation is related to variations in the fundamental frequency of pitch associated with an utterance. It depends on whether or not the intended utterance is a question, exclamation or declaration. Intonation also depends on the mood or emotional state of the speaker. There are language independent intonation tendencies [3, 9]; however, the intonation of Spanish has its own language dependent trends.

The routines necessary to produce a synthesized speech signal including automatic intonation assignment are shown in **Figure 2**.

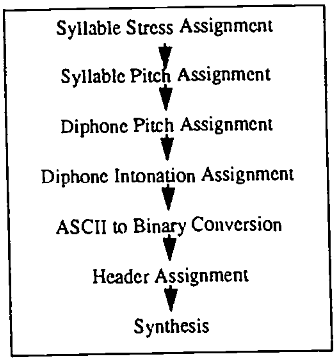


**Figure 2: Phases of the Automatic Intonation Assignment Routine**

At present, the program works for single words input to the system in addition to phrases or sentences with certain intonation patterns. Not every Spanish sentences entered to the system will end up with the correct intonation contour.

## DEVELOPMENT

*Syllable Stress Assignment*

One of three levels are assigned to a given syllable. Unstressed syllables receive a stress level of 0, syllables with primary stress get the value 1 and those with secondary stress are assigned 2. These values are used to assist the syllable pitch assignment procedure. The following is an example of the syllable stress values assigned to the word *amigo*.

| A | MI | GO |
|---|---|---|
| 0 | 2 | 0 |

*Syllable Pitch Assignment*

The next step is to assign pitch levels to each syllable. Values range from 1 to 5, where 1 is the highest pitch, 4 is the lowest, and 5 represents pitch levels of syllables with secondary stress (only those adverbs ending with *-mente*) whose frequency value is between 2 and 3. Two algorithms which are explained in [7] are considered depending on whether the user input a single word, or a sentence or phrase. Here is the syllable pitch values of the word *amigo*.

| A | MI | GO |
|---|---|---|
| 3 | 2 | 4 |

*Diphone Pitch Assignment*

Once the syllable pitch levels are determined, another algorithm maps these pitch levels to a corresponding frequency in hertz to each diphone of the word, sentence or phrase. The frequency value varies, depending on the desired age and gender of the synthesized voice. Two frequency values are associated with each diphone. After mapping the pitch level to its corresponding frequency value, a diphone structure is created.

For each diphone which ends in a vowel, a frequency of 5 hertz is added to the *f1* value of the first diphone containing that vowel. A frequency of 5 hertz is subtracted from the *f2* value of the successive diphone which begins with that same vowel, since a slight declination at the syllable level occurs [7]. The following is an example of the diphone structure associated with the word *amigo*.

| *Diphone* | *f1* | *f2* |
|---|---|---|
| 0a | 120 | 115 |
| am | 115 | 110 |
| mi | 135 | 130 |
| ig | 130 | 125 |
| go | 105 | 100 |
| o0 | 100 | 95 |

*Diphone Intonation Assignment*

An additional procedure scales the values obtained in the diphone intonation assignment routine into an ASCII file. This file contains the parameters which are later used to synthesize the concatenated speech. The columns of this file include the estimation of fundamental frequency.

The procedure begins by performing a formant analysis of the diphones, which correspond to the text entered by the user, using the WAVES+ **formant** command. Two files are produced with the extensions *.f0.sig* (fundamental frequency information) and *.fb.sig* (formant information). The scaling algorithm used to alter the fundamental frequency values of the *.f0.sig* file is explained in [7]. This algorithm scales the fundamental frequency values in a linear path.

*ASCII to Binary Conversion*

The file created by the diphone intonation assignment procedure must be converted from an ASCII file to a binary file. This is done by the **put_ddata** function of the Entropic Signal Processing System (ESPS) software utility.

*Header Assignment*

One last feature is required to complete the new binary file. Files with a *.f0.sig* extension usually have an associated header file. Headers are obligatory for the purposes of this project because it provides a facility to downsample the speech wave files. The sampling rate of the Spanish diphones is 20,200 samples per second, which is not compatible with the rate expected by ESPS (10,000 samples per second).

*Synthesis*

The last step of the automatic intonation assignment module is to synthesize the concatenated speech with the new intonation contours. This is done by using a source coding cascade formant synthesis program. The files with the *.f0.sig* and *.fb.sig* extensions are two of the parameters of the synthesis program.

## EVALUATION

The quality of synthesized Spanish speech was evaluated from 13 different Spanish proverbs. Compared to the pitch contour of the speech obtained by simply concatenating diphones, the contour of the resultant speech using the automatic intonation assignment routine is much more natural sounding.

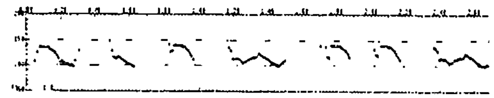

Figure 3: Intonation Contour of Diphone Concatenation

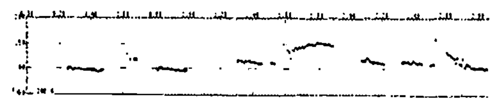

Figure 4: Intonation Contour with Automatic Intonation Contour Assignment

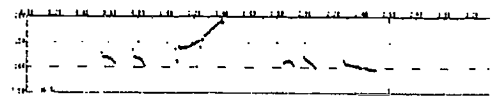

Figure 5: Intonation Contour of Natural Speech

Figure 3 shows the pitch contour of time-domain diphone concatenation. The frequency range of each word of the phrase falls within the same interval and is therefore monotone in nature. The intonation contour of Figure 4 is much closer to the original phrase, which is shown in Figure 5 because it includes the natural tendencies of rising on the last content word and sentence final falling on the last word of the phrase. The above figures all correspond to the proverb: *El que espera, desespera.*

## DISCUSSION

Even though Parlante produces satisfactory results, future development is needed. The system lacks many of the text preprocessing concerns such as number, abbreviation and acronym expansion. Also, Parlante does not consider two of the three prosodic features: rhythm and intensity assignment. Finally, testing and analyzing phases must be added to complete the system. The method of [2] emphasize the importance of testing the system for pronunciation accuracy as well as naturalness. Listening experiments like the ones mentioned in [4, 10] describe the techniques used to analyze the synthesized speech output.

Natural language continues to be the preferred medium for human/computer interaction. Further research in the field of speech synthesis will continue to enhance the quality of existing speech output devices.

## ACKNOWLEDGEMENTS

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# A Speech Device for People with Disabilities Using a Parallel Formant Synthesizer



**Katherine T. Samworth, BEE & Richard A. Foulds, Ph.D.**
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

## ABSTRACT

A speech synthesis device that is designed to meet the needs of severely dysarthric speakers or those who are unable to speak will be proposed. Background information describing parallel formant synthesis and the diphone inventory to be used will be presented. An algorithm to calculate parameters needed to run the synthesizer will be given. The device itself will be described with an update of the progress made on its development. An evaluation of the quality of speech that the device produces will follow.

## BACKGOUND

### Diphone Inventory

A diphone is defined as a segment of speech that forms the transition between two adjacent phonemes. Speech is recorded and diphones are then extracted from the time domain waveform and stored in an inventory. There are approximately 2800 diphones used in the English Language. Diphones can then be concatenated to create synthesized speech. The advantage of using diphones is that it allows for an unlimited vocabulary and it eliminates the need for complicated algorithms that are used to handle the transition between phonemes [1]. Diphones will be used in the speech device described in the design section.

### Formant Frequencies

The vocal tract acts as a resonant cavity causing amplification of some frequencies and attenuation of others[2]. In speech, the peak resonant frequencies are referred to as formant frequencies. These frequencies vary as the shape of the vocal tract changes. Speech signals can be partially characterized by a reasonably small number of formant values (typically 3 to 5 formants). Speech synthesizers using analog or digital resonators tuned to formant frequencies have been shown to produce reasonable speech output. Examples of these are the VOTRAX and DECTALK.

### Parallel Formant Synthesis

Formant synthesizers model the formant frequencies of the vocal tract. Each formant is modelled by a resonant filter that is excited by a periodic function which attempts to model the vibration of the vocal chords (this is called a pitch period or glottal pulse) and/or random noise which models turbulence that is caused by constrictions in the vocal tract. The pitch period represents voiced sounds (such as a vowels) and the random noise represents unvoiced sounds (such as the s or f sound). In parallel formant synthesizers, the resonators are place in parallel so that their sum produces the speech output [3].

Frequency domain synthesizers were developed as an alternative to time domain waveform encoders in order to decrease the data rate. Instead of having to store huge time domain waveform data files, formant synthesizers "attempt to preserve the short-term frequency spectrum of the signal" which changes slowly with time and therefore the update rates of the frequency parameters are much lower than that of time domain synthesizers [3].

In order to model the vocal tract in the frequency domain, a transfer function is written that describes the relationship between the output volume velocity at the lips to the input volume velocity at the glottis. Each term in the transfer function contains information about a particular formant frequency. The transfer function can be expressed as a product of these terms as in the cascade formant synthesis method. In the parallel formant synthesis method, the transfer function is expressed as a sum of terms. Equation (1) shows the transfer function in parallel. Each term includes the formant frequency (fn), the bandwidth of the frequency (bn) and the amplitude (An) of the frequency.[4]

$$(1)\ H(s) = \frac{A_1 f_1^2}{s^2 + b_1 s + f_1^2} + \frac{A_2 f_2^2}{s^2 + b_2 s + f_2^2} \ldots$$

When the parallel method is implemented, the bandwidth is usually chosen to be constant for all terms. The formant frequencies and the amplitudes of those frequencies must be specified. In most cases, no more than the first five terms of the transfer function are used since they contain enough information to synthesize speech without a detectable change in quality.

## STATEMENT OF PROBLEM

A speech synthesis device is needed for people with disabilites that includes the following features:

- is portable
- runs at a reasonable bit rate
- can be programmed to speak a particular voice
- produces a voice with that is 'natural' sounding

- is inexpensive
- has an unlimited vocabulary

## RATIONALE

A person who is severely dysarthric or who is unable to speak has need of a device that will allow effective communication. There should be few restrictions on the type of voice to use. If a person knows that he/she will be losing his/her voice due to surgery or progressive disease, he/she can have their voice recorded before they lose it. The synthesizer can then be modelled after his/her own voice. The bit rate must be fast enough so that speech can be produced in close to real time. It should be as natural sounding as possible.

## DESIGN

### The Proposed Device

The device will consist of frequency domain parameters of the diphone inventory stored in memory, a processing unit that includes a text to speech algorithm, a parallel input/output device, a parallel formant synthesizer and an amplifier. (see figure 1)

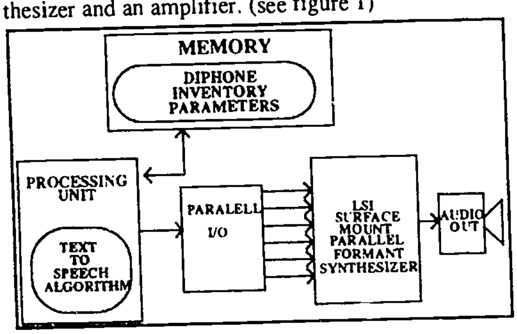


Figure 1

## DEVELOPMENT

### LSI Parallel Formant Synthesizer

The LSI synthesizer was chosen for the following reasons:

- its small size (the unit measures 2 x 2.5 inches) which will help to make the device portable
- it uses a low bit rate (6000 bits per second compared to 120,000 bits per second in the time domain)
- the diphone frequency parameters can be stored instead of storing the entire digital time domain waveform (150 bytes/diphone for frequency parameters compared to 3kbytes/diphone for time domain waveform)
- it allows for control of pitch which can help to improve the naturalness of the speech
- the amplitudes of the formant frequencies can be altered, allowing control of vocal effort and the ability to account for the antiresonant effect of the nasals [5]

For each 10 millisecond (ms) frame of speech, twelve parameters are fed to the synthesizer. They include formant frequencies, the amplitudes or intensities of the formant frequencies, the degree of voicing, and the pitch of that frame. The source of excitation in the LSI parallel synthesizer comes from a random noise generator and from a periodic glottal pulse generator. The random noise generator models the unvoiced parts of speech since they are non-periodic. Voiced speech is modelled by a periodic pulse generator which provides a waveform that mimics the natural glottal pulse.

There is a voicing switch that controls the degree of voicing of a particular frame of speech. Excitation mixers combine the voiced and voiceless signals together in order to account for the overlap that occurs in natural speech. When voiced and unvoiced sounds are mixed, it is typical that, the lower formants are largely voiced and that the higher formants are largely unvoiced. In the LSI Parallel Formant Synthesizer, each excitation mixture filter receives a common degree of voicing value. Each excitation filter has a different mixing fraction that determines the ratio of voiced to unvoiced speech that particular resonator will receive[5]. Figure 2 shows a schematic of the LSI Parallel Formant Synthesizer developed by Holmes [6].

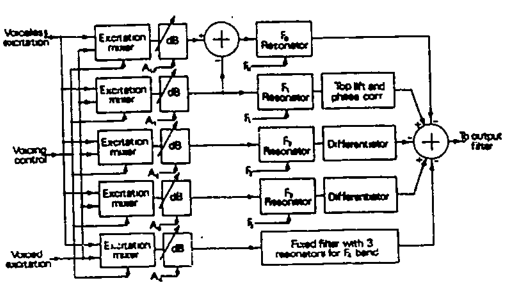


Figure 2

### Calculating Parameters to Run the Synthesizer

In order to get the synthesizer to run optimally, the correct parameters must be chosen:

Finding Pitch, Formant Frequencies and Degree of Voicing

The Entropic Signal Processing System (ESPS) (copyright 1990 *Entropic Research Laboratory, Inc.*) is used because of its accurate formant tracking program. We use it to generate formant frequencies, pitch and degree of voicing for each 10 ms frame of speech. This information is fed to the LSI synthesizer.

An Algorithm for Calculating Amplitude Values

The amplitudes or intensities of each formant frequency for each 10 ms frame of speech must be specified when using parallel synthesis. These amplitudes must be chosen carefully or distortion can occur. The authors have developed a program to calculate the amplitudes using MATLAB (copyright 1985-1989, by *The MathWorks, Inc.*). The steps to calculate the amplitudes are as follows:

1. Create a matrix of overlapping vectors of length 512. The center of each vector contains the time domain data from 10 ms of speech. The matrix size is 512 x #frames of speech.
2. Each vector is multiplied by a hamming window in order to decrease distortion when the fast fourier transform (FFT) is computed.
3. A Short Time FFT is computed by computing a separate FFT for each 10 ms frame of speech. The result is a vector of 256 real and imaginary amplitude values. The magnitude of the real and imaginary parts is found. Each value corresponds to one of 256 bins that range in frequency from DC (0 Hz) to the sampling frequency/2.
4. Formant frequencies are obtained from ESPS. These frequencies are "smoothed" across the unvoiced sections since these areas tend to be discontinuous which tends to increase distortion.
5. Using the formant frequencies obtained in 4., find to which bin each frequency corresponds. Assign each formant frequency a bin number. At this point there is a bin number corresponding to each formant for each time frame.
6. For each bin number in 5., multiply a cosine window (the length may vary) by the vector containing amplitudes of the appropriate time frame found in 3. (Note: The cosine window is used to obtain information that otherwise would be lost about spectral peaks near the frequency bin of interest. For example, 2 spectral peaks may exist on either side of the frequency bin chosen.) The center of the cosine window should be at the bin number for that particular formant frequency.
7. The values obtained in 6. are then summed, changed into decibels and scaled.

These amplitude parameters are fed into the synthesizer along with the formant frequencies, pitch and degree of voicing in order to produce synthesized speech.

### Producing Diphone Inventory Frequency Parameters

We are beginning the process of determining the frequency parameters for the diphones. We have taken diphones that make up the word "height", found each of their frequency parameters and concatenated them. The resulting word sounded almost identical to the original. We plan to continue this process for the entire diphone inventory so that any word can be spoken from the synthesizer.

### Text to Speech Algorithm

A text to speech algorithm has been written which will be incorporated into the device so that the user will be able to type in words and get speech out in close to real time.

## EVALUATION

The quality of speech from the LSI synthesizer has been evaluated. The synthesizer was tested using 8 different male voices and one childs voice. The synthesized version of the child's voice and 7 of the 8 male voices were intelligible and resembled the voices of the original speaker. There was some loss in quality between the original and the synthesized voices bu this loss was minimal.

## DISCUSSION

Many speech devices are available for the non speaking or dysarthric individual. However, these devices lack some features which many potential users feel are important. We are developing a new type of device that is designed to more closely meet the needs of these individuals. More work must be done in order to transfer this technology for clinical use.

## ACKNOWLEDGEMENT

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Katherine T. Samworth & Richard A. Foulds
Applied Science and Engineering Laboratories
Alfred I. duPont Institute
P. O. Box 269
Wilmington, DE 19899
Phone: (302)651-6830

9.1

# A Visual "Talk" Utility: Using Sign Language Over a Local Area Computer Network

Scott Galuska, M.S., Timothy Gove, B.S., John Gray, M.S.
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

## ABSTRACT

This paper describes how personal computers linked together in a local area computer network can be used for sign language communication between two people.

## PERSONAL COMPUTERS AND LOCAL AREA NETWORKS

In the past few years, computer technology once thought to be revolutionary have now become commonplace, especially in the workplace. In particular, two technologies have emerged that has revolutionized the workplace, the personal computer (PC) and the local area computer network (LAN).

PC's in the workplace have made the processing of information via spreadsheets and word processors as routine as using adding machines and typewriters were 20 years ago. Vast amounts of information once stored in filing cabinets are now available right on a person's desk.

While the PC gives a person a powerful means of manipulating data, the information gleaned from the data often must be passed on to other people. Here, a LAN is a powerful tool. By connecting PC's together in a LAN, people can exchange information electronically much faster than through a paper report or memo. Files can be sent from PC to PC for processing; memos can be sent to people via electronic mail (E-Mail).

## "TALK" UTILITIES

In the above scenarios, information is transferred passively. For example, when an e-mail message is sent from one person to another, the receiver can read the message at his/her leisure. Some systems also have utilities that allow two people to hold an interactive typed conversation over the LAN (an example is the UNIX "talk" utility). Typically, a utility of this sort will split the computer screen in half, with the top half of the screen echoing what a person types at one keyboard, and the bottom half echoing what a person types at the other keyboard. A conversation can then take place in English between two people using their PC's and a LAN.

A "talk" utility is in many ways analogous to a Telephone Device for the Deaf (TDD) conversation over a telephone line. Similarly to "talk", conversation is bi-directional, in real-time, and in a phonetic language.

For many deaf people, sign language is the preferred way to have an interactive conversation. What has been developed is a visual version of "talk", a utility that allows two people to have an interactive conversation using sign language through their PC's and a LAN.

## TRANSMISSION VIA THE TELEPHONE AND LOCAL AREA NETWORKS

Work has been ongoing for several years trying to solve the problem of transmitting sign language over ordinary telephone lines (Galuska, 90, Harkins, 91). The main problem with using telephone lines for signed conversation is the low bandwidth of the lines. In order to overcome that problem, severe image compression techniques, primarily edge-detection, are used to extract an outline of the person that can then be transmitted. This technique absolutely minimizes the amount of data needed for sign language communication.

By using LAN's instead of telephone lines, severe image compression techniques can be avoided. However, image compression techniques cannot be avoided completely, since a LAN has finite resources that all users on the network may need to access. A LAN will not allow full color, television quality images to be transmitted in real-time for signed conversation. Instead, grey-scale images are used. These images also use only a small subset of grey-scale values available to further compress the amount of data sent over the LAN. Images are spatially compressed to 64 x 64 pixels. At this time, images are being processed at approximately 15 frames per second; at 2K bytes per image, that is 60K bytes per second for a bi-directional conversation. Including overhead, approximately 7% of a LAN is being used at this time for a conversation. Further image compression techniques are being studied in order to minimize the amount of network resources used by a single conversation.

## SET-UP AND TYPICAL SESSION

Each person that wishes to use the visual "talk" utility needs an identical set-up. The current set-up entails an IBM-386 (or equivalent) PC, a VGA monitor and card, an inexpensive camera and card called the EDC-1000 made by Electrim, Inc. (Princeton, NJ), a link into a LAN, and the utility software. In the current set-up, a 1.5 Mbyte Ethernet LAN (IEEE standard 802.3) is used. For those that already have a PC and a LAN link, the only additional elements needed are the camera and the utility software.

A person using this utility would run it with the name (or address) of the PC that he or she wishes to contact. Assuming the second PC is running the utility software at the time, a message will appear on that screen informing the person that someone wants to "talk" to him/her. That person can then either answer or send a "rejection" answer to the originator. Should the person decide to answer, two images appear on the monitor, the person at the remote PC as well as the person at that PC. (The image of the person at the PC is mirrored in order to make it easier for that person to stay on camera.) Each person may then begin to sign to the other in conversation.

When the conversation has ended, one of the signers hits a key on the keyboard allowing the utility to shut down the conversation and listen for new "talk" requests.

## USES FOR A VISUAL "TALK" UTILITY

A visual "talk" utility can be used for point-to-point communication between two signers within the range of a LAN, especially in a work or academic environment. But perhaps an even greater use of the visual "talk" utility would be for remote interpretation (Galuska 1991). Should a deaf employee need interpretive services at a moment's notice, the employee can use the utility to access an interpreter at a remote location, who can then use a speaker-telephone to translate signing into a spoken language, and use the visual "talk" utility to translate spoken language back into sign.

## ACKNOWLEGEMENTS

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Scott Galuska
Applied Science and Engineering Laboratories
University of Delaware/Alfred I. duPont Institute
P.O. Box 269
Wilmington, DE 19899
Phone: (302) 651-6830
E-Mail: galuska@asel.udel.edu

9.2

# What Consumers Say Most Influences Their Assistive and Educational Technology Use

Marcia J. Scherer
National Technical Institute for the Deaf, and
International Center for Hearing and Speech Research
Rochester, NY

## INTRODUCTION

The use of both educational and assistive technologies in a wide variety of settings has increased tremendously in the past few years. For example, the Individuals with Disabilities Education Act of 1990 (I.D.E.A.) and the Americans with Disabilities Act (A.D.A.), both explicitly address assistive technologies. In all levels of education, such educational technologies as computer tutors and telecourses have expanded the options for addressing individual students' particular learning styles and needs. Yet, it remains a fact that consumers differ in their views about the value of technologies and in the degree to which they use them. What differences between successful users and unsuccessful users are related to differences in their predispositions to the use of a technology?

Because it is becoming increasingly important to understand the differences between those who successfully employ technologies and those who avoid or abandon their use, two instruments were developed to assess the quality of the match between a person and a particular technology. Both instruments are self-report checklists having a consumer-completed version and a professional version so that the degree of shared perceptions can be assessed. Items are of varied format, including 5-point Likert scales and checklists. The two instruments, the **Assistive Technology Device Predisposition Assessment (ATD PA)** and the **Educational Technology Predisposition Assessment (ET PA)** each have subscales so that characteristics of the technology, the individual's temperament, and the environment in which the person will use the technology can be separately assessed. The purpose of the instruments is to identify characteristics interfering with the use of a technology for a particular consumer.

The most immediate concern regarding the instruments is the extent to which they adequately assess relevant influences on consumers' predispositions to technology use (criterion-related validity). The description and results of efforts to address this concern regarding assistive and educational technologies for hearing-impaired persons form the primary objective of this research report.

## METHODS AND DATA SOURCES

Both the ATD PA and ET PA were created from the actual experiences of people who used or did not use a technology provided to them (1,2). The methods used to develop the instruments have been described in detail (3,4). The methods and data sources described here are limited to information collected to assess the instruments' validity with samples of individuals who are hearing-impaired.

<u>Hearing-Impaired College Students' Use of Educational Technologies</u>:

A. A pilot telecourse was offered Fall,1991 with students and faculty at Rochester Institute of Technology and Gallaudet University. The instructional delivery involved videotaped lectures and class discussions via electronic mail. All assignments were read and graded through the use of electronic mail. At the end of the course, students from each institution with the least course satisfaction and those with the most course satisfaction were interviewed with the ET PA content serving as the interview protocol ("contrasted groups" design).

B. A hypercard stack was created to augment an existing instructor-based, lecture/discussion course offered to first year science majors in need of improved study skills. The hypercard stack offers a self-paced method of instructional delivery. One module, Test Taking, was pilot tested with all 9 students enrolled in the Fall, 1991 science department Freshman Seminar. Evaluation sessions were conducted one-on-one and involved the students use of the hypercard stack. The computer screen was videotaped, showing cursor movements and choices as students moved through the stack. Following this, students completed a questionnaire that included the ET PA content.

Adults Use and Non-use of Assistive Listening Devices (ALDs):

A. Members of the Rochester area organization "Self-Help for the Hard-of-Hearing (SHHH)" were asked to complete the ATD PA regarding their use of ALDs. For the most part, people who are active in SHHH wear hearing aids and use a variety of ALDs. The mean age of the active members of this group is approximately 60.

B. The membership of an organization dedicated to the continuing education of older adults was also asked to complete the ATD PA regarding their use of ALDs. None of the individuals in this group wear hearing aids or use ALDs, but all have a demonstrated hearing loss The mean age in this group of persons is approximately 65.

Comparisons of the members of SHHH and the members of the continuing education organization formed a "contrasted groups" design.

RESULTS

Since the numbers of individuals in each study are small (approximately 10 people each), the data analysis is descriptive only.

Hearing-Impaired College Students' Use of Educational Technologies:

A. Those deaf students in the telecourse who have the poorest English skills reported the most dissatisfaction with the instructional delivery system and said they prefer face-to-face discussions where they can watch facial expressions. The students from each institution who had the least satisfaction said that they are intimidated by computers,that computer use interferes with their social activities, and that they did not have the background skills for the course. None of the most satisfied students reported intimidation or social interference, and all said that they ha᷊ the background skills for the ᷊urse.

B. While all students reported that the hypercard stack helped them learn "Test Taking" strategies and that they would use a similar mode of instruction again, those with the most satisfaction reported that they prefer working alone as opposed to working in a group, that they are often anxious, and that they generally see computer use as being fun. The least satisfied students reported just the opposite.

Adults Use and Non-use of Assistive Listening Devices (ALDs):

The members of SHHH and the continuing education organization, while similar in age, differ in degree of hearing impairment and the need for ALDs, with the SHHH members having more hearing loss and need for ALDs. In completing the ATD PA, the SHHH members reported a great deal of perceived benefit to ALD use, a belief that ALD use will increase their quality of life, and a view of ALDs as important in achieving their goals. The members of the continuing education organization reported the opposite. All individuals reported a good self-image.

## DISCUSSION

The ATD PA and ET PA seem to have done a good job of discriminating predispositions to technology use on the part of satisfied and less satisfied users.

As the use of assistive and educational technologies increase, there will be more concern directed towards their quality, selection, and the ways they impact overall quality of life. It is important for professionals to be able to analyze the constellation of factors serving to influence the individual's predisposition toward technology use or non-use so that the most appropriate technologies for that person can be provided. Based on these results, professionals in the field have two self-report, checklist, instruments available to them, both of which have reasonable validity. The ATD PA and ET PA can be useful in the earliest stages of matching person and technology, in identifying needed modifications, and in reducing the disappointment and frustration that often accompanies a poor match between individuals and the technologies meant to help them. Their use can also help reduce abandonment or reluctant use of technological assistance, decrease premature or inappropriate technology recommendations, and help assure that those persons who can most benefit from a technology will receive and use it. Additionally, the documentation of initial and post intervention profiles can help provide the rationale for device funding or training, demonstrate improvements in skills and capabilities over time, and organize information about the needs of an organization's consumer or student population. A current and complete description of the instruments is available (1).

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Marcia J. Scherer
National Technical Institute for the Deaf
and
International Center for Hearing and Speech Research
1 Lomb Memorial Drive
Rochester, New York 14623

# OPEN DOCUMENT ARCHITECTURE - AN OPPORTUNITY FOR INFORMATION ACCESS FOR THE PRINT DISABLED

Tom Wesley & Nick Ayres
Department of Computing
University of Bradford
Bradford, United Kingdom

## ABSTRACT

The difficulties of access to printed and electronic information faced by the print disabled are discussed. A distinction is drawn between formally and informally published information, the relevant International Standards being SGML and ODA. An outline of ODA is given and the ways in which the adoption of this Standard could improve access to information by the print disabled are described.

## BACKGROUND

A significant group of disabled and elderly persons have difficulty in accessing the printed word. This print disabled group includes the blind, the deaf blind, the visually impaired, the dyslexic and those with motor impairments which make it difficult to physically control paper documents. Historically, the print disabled obtained what little information they could through highly specialised media, such as braille, whose production had little relationship to the mechanisms used for the print enabled. This inevitably severely restricted the quantity of information easily accessible to the print disabled.

The advent of computer and information technology has revolutionised the access to information by the print disabled. Most hard copy braille is now computer produced with a consequent considerable increase in the amount available. Information stored on computers can be accessed by soft braille and enlarged print displays and speech synthesis. Furthermore, as the computer has become an essential part of everyday life, both in the workplace and at home, the print disabled are not excluded from the developments but can use the technology in similar ways to the print enabled. Compared with the information available to the print disabled before the advent of computer technology, that available now is truly astonishing.

## THE PROBLEM

However, compared with the amount of information available to the print enabled, that easily accessible to the print disabled is tiny. To understand the nature of the problem it is helpful to divide printed information into two major categories—formally published and informally published information. In practice there is a broad continuum of different kinds of information, but our categories are two important end points in the spectrum.

*Formally published information*
Formally published information includes books, newspapers, magazines, learned journals, and increasingly their electronic counterparts distributed on, for example, CD-ROM.

Only a tiny proportion of formally published information is easily accessible to the print disabled. It is ironic that virtually all formally published information is computer produced and therefore, given appropriate technology, transformations could enable widespread production of the information in a form suitable for the print disabled. However, the lack of appropriate standards for electronic information has meant that it has been very difficult to produce braille from compositor tapes. Thus braille books are rarely produced directly from the original electronic form, relying instead on a significant manual effort.

For formally published information in electronic form, there is more direct access. Here however, the problem lies in the presentation of the information. Many of the print disabled have great difficulty in navigating through large amounts of information, since they lack the ability to rapidly scan a page or screen. The software access systems used for electronically published information generally assume the user has scanning ability and often use graphical user interfaces. Thus, although electronically published information is physically accessible, it is in a far from ideal form for the print disabled.

*Informally published information*
Informally published information is the world of the word processor and desk top publishing. Here, away from the constraints of copyright, information flows freely and rapidly within restricted domains such as a company or an individual office. Documents are produced rapidly, often having importance over a short time scale.

If the print disabled person has access to the electronic document and uses a compatible computer hardware and software system to that on which the document has been produced, much of the information can be accessible. For many print disabled people the access to graphical information presents particular difficulties, but textual information is generally accessible.

However, similar difficulties to those noted for formally published information exist—namely, the lack of standards for electronic information storage, the difficulty of navigating a large document and the increasing presentation of information in graphical formats.

It is our firm conviction that the development and adoption of International Standards of electronic information storage is a key factor in enabling the print disabled to gain much more widespread access to the majority of information which the print enabled take for granted.

## THE INTERNATIONAL STANDARDS APPROACH

Fortunately, a powerful standardisation movement is developing. Two ISO standards have emerged, corresponding to our categories of formally and informally published information. The Standard Generalized Markup Language (SGML) is being used increasingly in the publishing world (1), (2). Its potential for braille production was recognised by Kaysen (3), but there appears to have been no practical follow up. Recently, Engelen and Wesley (4) have discussed the wider implications of SGML for the print disabled.

The International Standard corresponding to our informally published information category is Office Document Architecture (ODA), also known as Open Document Architecture (5) (6). ODA, a more recent standard than SGML, has so far attracted little attention outside the groups actively involved in its development. As far as we are aware, the present paper is the first published discussion of the relevance of ODA to the print disabled. In the next section we present a broad overview of the ODA, before outlining its potential for the print disabled.

## AN OVERVIEW OF ODA

The underlying philosophy in the development of ODA has been to enable the standardisation of the structure of electronic documents so that they can be transferred between different hardware and software systems without any loss of content and formatting information. This transferability would allow a document to be produced on a particular word processor, be transferred to a completely different system where it could be further edited before being passed back to its originator. Furthermore, the content should not be restricted to simple text but should encompass all major types of information and be expandable to meet as yet unknown content types. Given these ambitious aims, it is not surprising that the ODA Standard is both long and complex.

ODA recognises that there are two ways of looking at a document, the 'logical' and 'layout' points of view. The logical view is the splitting of the document into objects that have human meaning such as 'titles', 'paragraphs' and 'figures'. This is independent of the representation on screen or on paper.

The layout view recognises that the same logical structure can be laid out on screen or paper in many ways. This paper for example is in two columns but could easily be in one column and still be the same 'logical' paper.

ODA itself does not define the logical objects such as 'paragraphs' but provides the facility for their definition. In doing this ODA allows the definition of 'generic documents' which are document templates. Thus it would be possible to have a template for a paper to be presented to this conference stored electronically using ODA. This template could be for both the logical format, so that the abstract appears in the correct sequence relative to the first paragraph, and for the layout so that the paper is in two columns.

The third major component of an ODA document is its content. Content is structured into an extendible set of content architectures. Content architectures currently defined are text, raster (facsimile) graphics and geometric graphics, the definitions using existing ISO standards. Work is well advanced on the definition of architectures for sound and hypertext.

Four main structures within ODA are used to split the definition of the document in recognition of the two different views. They are the 'specific logical structure', 'generic logical structure', 'specific layout structure' and 'generic layout structure'. The structures are defined hierarchically and often represented as trees.

The generic logical structure and generic layout structure can be used during editing and layout as the templates for a document. They define the types or classes of objects that can appear in a document. The specific logical structure and specific layout structure record how instances of the classes defined in the generic structures are related in the document. The specific layout structure records how the content of a document is placed in 'blocks' which are rectilinear areas on a page or screen. One or more blocks are placed in 'frames' and can then be placed as a whole. Frames can hold other frames. One or more frames are placed in 'pages' which are in turn placed in 'page sets'.

The layout process is split into two operations, the document layout process and the content layout process. The document layout process deals with the placing of blocks, frames, pages and page sets for portions of content and produces the specific layout structure. The content layout process deals with the layout of the portions of content within the allocated blocks.

The generic layout structure deals with how the frames, pages and page sets (but not the blocks) and different categories of contents are placed together. With each frame defined in the generic layout structure there is an attribute called 'permitted categories'. During the layout process, only logical objects whose attribute 'layout category' has the same name can be placed in that frame. This can be used, for example, to group a title and author into a frame separate from the subsequent paragraphs, by giving the title and author objects a layout category of 'header' and the paragraphs 'body'. The corresponding frames would have these as their permitted categories.

**IMPLICATIONS OF ODA**

In this section we outline some of the ways in which the widespread commercial adoption of ODA would be beneficial for the print disabled. Only time will tell whether ODA becomes widely used, but there are encouraging signs. A commercial group, the ODA Consortium (ODAC), with representatives from many major hardware and software suppliers is developing software tools for the creation and manipulation of ODA documents. It is hoped that these tools will become generally available during 1993. The first stage of commercialisation is likely to be conversion routines whereby existing word processors can interchange via ODA. In the long term the development of native mode ODA word processors can be expected.

*Standard Information Interchange*
An obvious advantage of ODA for the print disabled would be the widespread availability of information in a standard format, or easily convertible to the standard. This conversion would preserve both logical and layout information. The only general method of conversion at present is to drop down to raw ASCII text, thus losing all the extra information implied by the layout.

*Fully formatted braille*
Currently the professional formatting of braille generally requires considerable specialised manual intervention. The separation in ODA of the logical structure from the layout structure allows several views of the same contents to be provided. Thus, with appropriate interfaces, fully formatted braille views, reflecting different braille systems could be incorporated into ODA structured documents.

*Document Navigation*
The standardised method of structuring the contents of electronic documents in ODA means that it will be possible to make the structure available to the print disabled user. This should allow the user to obtain an orientation overview, to scan documents and to have access to automatic indexing for retrieval purposes. The capabilities of document navigation should be dramatically enhanced with the incorporation of hypertext into ODA.

*Access to Graphical Information*
It is difficult for many print disabled people to access graphical information. Apart from the inherent problems posed by the nature of their visual impairment there has been the difficulty that graphical information has not been available in a standardised form. The ODA content architectures allow access to standardised geometric graphical information creating the possibility of text and voice annotations of graphical structures and the development of systems to simplify graphics for display on pin matrix devices.

*Creation of well formatted documents*
The implementation of document templates within ODA provides a powerful mechanism for the print disabled to create well formatted documents without assistance from others.

**THE CAPS PROJECT**

The Commission of the European Communities has recently initiated a Technology Initiative for Elderly and Disabled people (TIDE). Within the TIDE programme, the CAPS project (Communication and Access to information for People with Special needs) is investigating the potential of both SGML and ODA for improving access to information for the print disabled. Prototype applications will be created so that the print disabled will be able to use electronic information stored in SGML and ODA when it becomes available, rather than having to wait the usual long time for the appropriate interfaces to be developed.

**ACKNOWLEDGEMENT**

This work has been partly funded by DGXIII of the Commission of the European Communities under its TIDE initiative.

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Dr Tom Wesley
Department of Computing
University of Bradford
Bradford BD7 1DP
United Kingdom

# AN ELECTROLUMINESCENT AID FOR LOW VISION READERS

Steven H. Fazenbaker and Gale R. Watson
Veterans Affairs Medical Center, Decatur, Georgia

## ABSTRACT

Many persons with visual impairments require the use of above average lighting levels for visual task performance. Low vision readers often use high powered magnification devices with short focal distances. Because they must place their heads close to the text, additional lighting often must be used. Preliminary research has shown that electroluminescent (EL) lamps can provide such lighting for persons who employ 8X-20X magnification when reading. Because EL lamps have an extremely thin profile, it is possible to place one between the low vision reader and the printed page without restricting the reader's ability to get close to the page. In addition, EL lamps remain cool to the touch, provide even illumination, are portable, and produce almost no IR or UV radiation.

## INTRODUCTION

For the thousands of individuals with low vision, loss of the ability to read and write can be devastating. The opportunity to read mail, balance a checkbook, scan the daily newspaper, or read for pleasure, may be denied to the person with low vision. This results in the loss of participation in activities of daily living, loss of vocational and avocational activities, and loss of independence. Fortunately, there are devices available that magnify the text to allow persons with low vision to take full advantage of their remaining vision.

As the required magnification increases, the distance that the reader must be from the printed page decreases. As the reader gets closer to the printed page, however, his or her head blocks more and more ambient light. Also, as the distance between the reader and the page decreases, it becomes more difficult to position lighting so that it illuminates the page.

Additional lighting is usually provided in the form of incandescent or fluorescent light bulbs. Unfortunately, incandescent bulbs produce considerable heat, and the harsh light and flicker of fluorescent bulbs are unpleasant to many individuals. Furthermore, both light sources provide uneven lighting, and their size limits how close the reader can get to the page.

## DESIGN/METHODOLOGY

Electroluminescent (EL) light technology shows great promise in overcoming the problem of illuminating reading material for persons using high magnification. EL lamps have an extremely thin profile, and therefore do not limit how close the reader can get to the page. Furthermore, EL lamps provide even lighting over the entire surface-in-view, they remain cool, they are portable, and they produce almost no infrared or ultraviolet radiation.

An EL lamp is being developed to meet the following criteria:

* It will provide the same intensity of incident light as incandescent and fluorescent bulbs at close distances.
* It will not impose an unnatural posture on the user.
* It will not produce significant glare.
* It will remain cool to the touch throughout extended use.
* It will provide sufficient light, eliminating the need for any other lighting.
* It will increase contrast and diminish light scatter by emitting only longer wavelengths.
* It will offer an adjustable light level.
* It will be durable.
* It will be powered by a safe and inexpensive power source.
* It will be inexpensive to produce.

ELECTROLUMINESCENT READING LAMP

Three configurations are being developed. One configuration will be designed to clip onto a pair of spectacles. The second configuration will be used as an insert into a stand magnifier. The third configuration will be used to provide backlighting while filling out forms.

RESULTS

At the time of writing, a prototype unit had been constructed. A 9-volt battery and a solid-state inverter produce 120VAC at 400Hz to energize the lamp. This is the voltage and frequency specified by the EL lamp manufacturers. Although the low wattage produced by the 120VAC power supply is completely safe, it is capable of producing an unpleasant shock in the event of damage (broken or exposed wire between the lamp and power supply). For this reason, an attempt is being made to produce equal illumination by decreasing the voltage and increasing the frequency of the power supply. An attempt is also being made to replace the 9-volt battery with a battery that has a higher amp-hour capacity/size ratio.

The prototype unit has been mounted to a +20 diopter lens for demonstration purposes. Several visually impaired individuals have used the prototype. Their feedback has been very favorable. The users specifically mentioned the increase in lighting over room light alone and the heightened contrast the EL lamp gave to reading material.

Work is continuing to make the prototype match the design criteria described above.

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Steven H. Fazenbaker, Gale R. Watson
Veterans Affairs Medical Center (153)
1670 Clairmont Road
Decatur, GA 30033

# Computerized Form-Filling System Design Using Voice Output: A Case Study

Kathleen Beaver, Education Specialist
University at Buffalo

## Introduction

Filling out forms is an everyday routine for most of us. Time sheets, supply requisitions, purchase orders, questionnaires and applications are just a few of the forms we use regularly. In fact, form-filling is so routine, most of us do not pay much attention to the enormous amount of information contained on a form or the complexity of the form design itself. Check lists, columnar data entry and systematic placement of information simplify the form filling process. But this is not the case if you are blind.

For each unit of information placed on a form, the form filler must have access to: (1) what information is being requested, (2) the format of the information, (3) the allowable length of the information, (4) the exact placement of the information (row and column number), and (5) if the unit of information is linked to other information on the form. Without a computerized form-filling system with voice output, filling out forms can become an obstacle to securing and maintaining employment. This was the case for Colleen, a social worker with an MSW who recently lost all functional vision.

Colleen is a counselor in the detoxification unit of a major hospital in a large city. The most important aspect of Colleen's job is the completion of an extensive intake/assessment form through interview of those entering the detox program. The intake form is eighteen pages long and was developed within the hospital by the professional staff of the unit.

## Methodology

### Design

The goal of the system design was to provide Colleen with a method to independently use her computer and voice output system to interview and to complete the eighteen page intake assessment form.

To accomplish this goal, it was necessary to: (1) analyze each page of the form, (2) choose an efficient form-filling program that was compatible with her computer equipment and voice output system and could accommodate the complex form design and (3) become familiar with the advanced features of the voice output system software.

### Components

Colleen has an IBM compatible 386 computer with the CompuSight Apollo Portable Speech System available from Electronic Visual Aids Specialists.[1] The form-filling program selected was FORM-MATE marketed by the Henter-Joyce Company.[2] Colleen's printer is a Hewlett Packard DeskJet 500 inkjet printer.

The CompuSight speech output system has very powerful software that automates the loading of multiple voice environments based on screen characters. A voice environment is defined as a set of user-selected options chosen to optimize the audio feedback of screen-displayed information. Each set of selected options can then be stored on disk as a file.

The FORM-MATE form filling program is designed to work well with speech output. It combines three user-created files, a "prompt" file, a "form" file and a "control" file, used in conjunction with a voice output system into a form-filling system for individuals who are blind. The "prompt file" provides speech access to the information being requested as well as the maximum length and format required and can be designed to redirect the flow of the prompts based on the presence or absence of a previous response. The "form file" directs each piece of information to the appropriate row and column placement on the printed form. The optional "control file" can alter the print size, font and attributes of the printer characters.

**Process**

Using advanced features of the CompuSight Speech Program, a set of voice environments were created for use with the FORM-MATE form filling program. These environments were designed to provide voice access to each prompt, error message and program menu selection. It was also designed to enable Colleen to review and edit previously entered information. Colleen was then instructed in using the FORM-MATE program.

A form file was created for each of the eighteen pages. Exact placement of each unit of information needed to be designated by using the required syntax of a pair of ^ symbols surrounding a letter and then a number. Each placement designation had to be unique. (FIGURE 1.)

Next, a prompt file for each page was created using the appropriate placement designation symbols defined in the form file. The creation of the prompt file required in-depth analysis of the form and Colleen's familiarity with the form and her input was essential. (Figure 2.)

Each page was then loaded and executed according to the FORM-MATE instructions. If there were any mechanical errors detected in either the form file or the prompt file, the program displayed an error message and the program terminated. The form file and/or the prompt file then needed to be examined for errors and correction before retesting.

Finally, each page was tested by Colleen and examined for logical errors. For example, did each prompt provide her with enough information to ask her patient the appropriate question? Did the redirection of prompts make sense and work properly when a previous item was left blank? Were all items defined using adequate field length?

**Results/Discussion**

The form filling system created for Colleen has enabled her to independently interview clients and complete the eighteen page intake/assessment form. She is currently in private practice and with permission of the hospital, uses the form daily. Without this form-filling system, Colleen would not be working as a drug rehabilitation counselor.

The process of creating, debugging and testing this eighteen page form was extremely time consuming. In addition to the steep learning curve involved in mastering the FORM-MATE program and creating the voice environments for the CompuSight speech system, fifty hours were spent calculating the exact placement of each piece of information, analyzing the data, typing the form files and the prompt files, debugging the mechanical errors and correcting the logical errors. Attention to detail was crucial.

While the end product does enable someone who is blind to independently fill out and print complex pre-printed forms, the creation of the form files requires assistance by a sighted individual.

**Acknowledgements**

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**Footnotes**

[1] Electronic Visual Aid Specialists
16 David Avenue
P.O. Box 371
Westerly, RI 02891

[2] Henter-Joyce, Inc.
10901-C Roosevelt Blvd.
Suite 12000
St. Petersburg, FL 33716

Address
Kathleen Beaver, Education Specialist
515 Kimball Tower
University at Buffalo
Buffalo, NY 14214, (716)831-3141

**FORM FILE EXAMPLE**

```
PRIMARY COUNSELOR  ^a1                  ^  PHYSICIAN  ^a2              ^

DEMOGRAPHICS:

LAST NAME ^a3                 ^  FIRST NAME ^a4               ^  M.I. ^a5^

ADDRESS ^a6                          ^ ^a7  ^   ^a8          ^ ^a9^  ^a10^

SOCIAL SECURITY NO. ^a11       ^         SEX:  FEMALE ^a12^  MALE ^a13^

RACE (CHECK APPROPRIATE ITEMS):ALASKAN NATIVE ^b1^ NATIVE AMERICAN ^b2^

 ASIAN ^b3^  BLACK ^b4^  WHITE ^b5^  HISPANIC ^b6^

 (IF HISPANIC) PUERTO RICAN ^b7^  MEXICAN ^b8^  CUBAN  ^b9^ OTHER ^b10^
```

Figure 1.

**PROMPT FILE EXAMPLE**

```
DEMOGRAPHICS PAGE
a1 COUNSELOR
t
Enter the name of the counselor

a2 PHYSICIAN
t
Enter the name of the admitting physician

a3 LAST NAME
t
Enter the patient's last name

a4 FIRST NAME
t
Enter the patient's first name

a5 INITIAL
t
Enter the patient's middle initial

a6 STREET
t
Enter patient's street number and name

a7 APARTMENT
t
Enter patient's apartment number

a8 CITY
t
Enter the patient's city

a9 STATE
^X
Enter patient's two letter state abbreviation

a10 ZIP CODE
z
Enter patient's zip code
```

Figure 2.

# A Study of Accessibility to Electronic Music Synthesizers and Sequencers by Blind Musicians

Jay Williams, John Brabyn

The Smith-Kettlewell Eye Research Institute
San Francisco, California

Abstract

A large number of blind persons earn their livelihood through music. The goals of the study are to explore methods by which state-of-the-art music synthesizers and their associated sequencer programs, normally run on personal computers connected to the synthesizer via the MIDI interface, can be accessed by blind users.

## Background: The Problem

Within the last ten years, as manufacturers have incorporated microprocessors and memory capabilities into their products, more and more computer-based equipment is reaching the marketplace. Many of these systems present accessibility problems for the blind (e.g., bank teller machines, point-of-sale systems, music synthesizers, etc.).

Since 1983 virtually all electronic music synthesizers and their associated sound processors, as well as much of the sound mixing and recording equipment, employ "MIDI" (Music Industry Digital Interface), a digital language which allows "communication" between one device and another, as well as with a computer. Thanks to these improvements, these instruments can achieve immeasurably greater subtlety of expression, and allow changes in real time which could previously be accomplished solely by modifying a recording of an electronic "synthesizer." However, the advent of these digital instruments (synthesizers, samplers, and their associated sound-processors) has presented, for the first time, the problem of mastering a musical instrument without the benefit of sight.

To illustrate the problem, one can envisage a piano with the usual three pedals, but each pedal has two dials associated with it. Suppose you press the soft pedal and nothing happens except that a visual display lights up and asks you to turn the two dials to select the highest and lowest notes of a group which you wish to soften. As you turn the dials, numbers indicate, from 1 to 88, which notes will be affected. Once you have selected the range to be softened, you press an "enter" button. Now, right above the soft pedal is a smaller pedal. Press it, and the soft pedal reverts to affecting the whole keyboard. Press the smaller pedal again, and you again affect the smaller range you set by those two dials.

Thus, on a modern synthesizer each control switch can perform a host of functions, depending upon which of its menus is chosen. Further, the newer synthesizers and samplers resemble pipe organs in that they contain several distinct "instruments" which can be played simultaneously. A computer is often used to store data for "playing" the music, and data which dictates the synthesizer's sound characteristics. Except for very sophisticated installations, the computer does not generate the sound itself -- it plays the synthesizer much as a piano roll plays a player piano. The program for doing this is termed a "sequencer" and, because the musician may use the program to play only a portion of the piece, the computer-generated part is termed a "sequence." The software which contains the data that constitutes a synthesizer's instrument parameters is called a "patch librarian." Such a program can have many different files, each of which contains a different set of sound parameters. These can be used with a synthesizer which is "programmable" -- that is, its "patches," or "voices" can be reprogrammed to have parameters other than those which the factory first installed. Access to all these features can become very problematic for the blind operator.

## Investigation of Present Employment Status of Blind Users

We have contacted a number of blind musicians who earn their living in music using electronic equipment. Those contacted to date have avoided areas of employment in which on-the-spot changes in synthesizer settings requiring the ability to see the display are a critical factor. Rather, they focus on the creation of music which is destined to be recorded. In these instances the extra time needed for familiarization with and operation of the equipment does not significantly impinge on someone else's time. We have identified several potential areas of employment such as teaching and work in automated recording studios which might require on-site use of pixel-based computers and other more difficult systems. Our investigations indicate that these situations may be made more tractable by the inclusion within recent music-sequencing software of "standard MIDI files." This serves the equivalent function of converting text in a word processor into an ASCII file. The music can be played independent of any particular software. If further revision is desired, the "sequence" can be reconfigured into another sequencing program.

## Investigation of Access to Instrument Displays and Controls

A major reported difficulty among blind musicians is not so much with the use of the computer in arranging the music, but with the mastery of the electronic musical instruments themselves. Without access to the information on the instruments' displays, a blind musician cannot "fiddle" with the instrument in the store to obtain an idea of its features. Some instruments afford further discouragement in the form of a control panel which is absolutely smooth to the touch. Although blind users usually have a gridwork laid over the panel to demarcate the positions of controls, no real use can be made of the instrument until this is done. Those musicians who are Optacon users can read some displays if they use LEDs (light-emitting diodes). They can also use the Optacon to browse through equipment manuals, but this is only a partial solution. An example of what can happen without feedback from the display is the following report from a blind user:

*"I pressed a key, I got nothing. After setting parameters which should guarantee the presence of a sound, I still had nothing. The display was telling me all the time that the sound had its time-delay set to #127, which meant the sound wouldn't happen for 30 seconds. However, this isn't a function I used often enough to think of immediately. Finally, while innocently resting my finger on that key, thinking what to do next, the 30 seconds concluded and the music came out of the speaker."*

Often, if a blind user becomes disoriented by an erroneous button-push, the only practical solution is to "power down and reboot" the synthesizer, to ensure that such an error will not be stored in the machine's memory.

We have explored possible solutions to this problem including the use of a program developed by Michael Williams of France for the Atari line of computers which extracts this type of information via the synthesizer's MIDI port and presents it on the computer screen at the moment it changes. As part of the present study, we are also exploring other methods of instrument display access and plan to document and rank a range of available synthesizers in terms of their relative difficulty for blind operators in this regard, as well as contacting manufacturers to alert them to difficulties in access to their machines.

## Evaluation of Suitable Computer Access Methods for Sequencer Operation

Access to the computers used to control and monitor the modern synthesizer presents special problems. With the exception of "Outspoken," a program which allows the blind user of a Macintosh to navigate with keyboard commands instead of mouse movements, non-visual screen access is limited to text material. (Moreover, a blind programmer at Berkeley Systems has found conflicts between "Outspoken" and a popular music-sequencing program, "Performer.") In strictly creative terms this is not yet an issue, as there are some excellent text-oriented programs for use with IBM PC compatibles. To date we have tested three sequencer programs: Cakewalk, Miditrack III from Hybrid Arts, and Sequencer Plus III from Voyetra Technologies.

In our accessibility evaluations of Sequencer Plus III, one of the most popular sequencer programs, we have tested its use with several screen access programs for the blind, including JAWS, Video Voice, Vos, SKERF-Pad, and Provox. With the exception of the SKERF-Pad, these programs use keyboard commands to perform the various reading functions. They differ in such strategies as the creation of "windows," modification of speech parameters, the identification of video characteristics, and the types of information which will be spoken automatically. We have documented their performance in this application and the occasional conflicts between keystrokes in the screen-reader and the application program -- along with methods of resolving these problems.

The SKERF-Pad offers a different approach. It uses the Touch Window, a touch-sensitive tablet equipped with an overlay which contains raised lines (one for each line on the screen), and a number of "boxes" which serve as controls. It has been found to be particularly useful in this application because of its replication of screen "geography" and its transparency to the application software. It is also convenient to use in conjunction with one of the other, more conventional, screen readers. The SKERF-Pad makes the constant jumping around the screen easy to monitor, while the alternative screen readers, used as back-up, provide for the automatic speaking of material which changes as commands are issued.

## Summary of Results to Date

We have now evaluated several music sequencer programs for the IBM PC and compatibles, in conjunction with several screen access systems for the blind, and have found techniques for making at least a majority of the sequencer features accessible.

As a result of our discussions with Voyetra Technologies, backed up by input from other blind users of electronic music synthesizers, the company now supplies on computer disks the manual for their SP GOLD sequencer program.

Our music synthesizer/computer/sequencer system (Figure 1) has been used in demonstrations to such bodies as the California Transcribers and Educators of the Visually Handicapped, to raise awareness that blind persons can gain access to such equipment using modern technology.

We have also investigated access to software which prints music from MIDI data and which will also play back from a score after its data is entered in. Several possible solutions to this problem are under exploration. For example, a collaborator at the Berklee School of Music in Massachusetts, Jack Jarrett, has developed a program called Music Printer Plus for the PC. It does not utilize

Figure 1.

Synthesizer/Sequencer Access
Test and Demonstration System

Windows, and in general, he wishes it to be easy for musicians to use. Voyetra Technologies is supporting his software, and he is collaborating with us on making such a program usable for blind musicians (and other disabled musicians who must access the computer by means other than a keyboard).

Work has begun on an accessibility manual for blind musicians, to assist persons wishing to use modern synthesizer equipment in their jobs or pastimes. We have published a series of articles in braille, cassette, and computer disk versions[1] on this subject, including articles on equipment and definitions, synthesizer history and features, the MIDI interface and language, software sequencer access, and sources and resources. Much of this material will be adapted for later separate publication and distribution to blind musicians.

Collation of the information from all of these efforts into a handbook for blind musicians covering equipment and software selection, advantages, limitations, and use is planned.

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## Author's Address

Rehabilitation Engineering Center
The Smith-Kettlewell Eye Research Institute
2232 Webster Street
San Francisco, CA 94115

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# OPTACON "READING": THE EFFECTS OF TACTILE STIMULUS COMPLEXITY AND MOTION FACTORS

Karsten A. Loepelmann & Eugene C. Lechelt
Department of Psychology
University of Alberta
Edmonton, Alberta, CANADA, T6G 2E9

## ABSTRACT

Motion direction of vibrotactile patterns presented to the fingertip via the OPTACON was examined using lines, 'nonsense' symbols, and letters. Discriminability of motion direction increased as the stimulus onset asynchrony (SOA) between the successive stimulus "frames" that produced the percept of motion increased. Also, SOA interacted with stimulus display time. The results are interpreted in terms of stimulus masking and temporal integration. Implications for sensory substitution and the visually impaired are discussed.

## BACKGROUND

When the skin is used as a sensory substitute for vision, it is critical that the stimuli are presented in a way that is maximally compatible with the tactile modality (1). To achieve this goal, it is imperative to determine what constitutes a 'good' stimulus pattern (3). The OPTACON is a commercially available reading aid for the blind that can present printed text or spatio-temporal patterns tactually to the fingertip (2). It is essential to delineate the elements of vibrotactile stimulus patterns that make them maximally discriminable, rather than to assume that the tactile sense can function as an extended retina.

## RESEARCH QUESTIONS

The purposes of this study were to investigate the effects of (a) stimulus complexity and meaningfulness, and (b) the temporal variables SOA and display time on discrimination of motion direction of vibrotactile stimuli, as these are critical dimensions in the processing of OPTACON stimulation

## EXPERIMENT 1 METHOD

Subjects: Four sighted participants (one female, three male) with no formal OPTACON training served as observers.

Apparatus: An OPTACON (OPtical-to-TActile CONverter) tactile display interfaced with an IBM PC XT microcomputer was used to deliver stimuli. The OPTACON's display consists of a matrix of piezoelectric bimorph reeds or "pins" (6 column by 24 row array) vibrating at 230 Hz.

Stimuli: In Experiment 1-A, stimuli consisted of vertical bars that were 1pin wide by 10 pins high. Each bar was "scrolled" or moved right or left across the width of the matrix (six pins). In Experiment 1-B, stimuli were horizontal bars six pins wide by one pin high, scrolled up or down across the upper 10 pins of the matrix. Note that the area defined by scrolling in Experiment 1-A (10 x 1 pins, scrolled horizontally by 6) is equal to that in Experiment 1-B (1 x 6 pins, scrolled vertically by 10). Because the spacing of pins is denser vertically than horizontally, a 6 x 10 pin matrix has an area of about 11.0 x 11.25 mm and forms an approximate square.

The motion obtained on the OPTACON display was achieved by presenting the stimuli in a sequence of discrete steps or "frames." After onset of a stimulus frame, there existed a brief temporal delay before the frame was replaced by the succeeding frame, in which the relative position of the bar changed by a small amount (i.e., by one pin in the desired direction of motion) from the previous position. The result of successive presentations of these display frames was a percept of motion.

Presentation of stimuli using the OPTACON is conventionally described in terms of display time, defined as beginning when the bar appears on one side of the matrix, and as ending when the bar exits the opposite side of the matrix (3). However, due to the difference between horizontal and vertical pin density on the display matrix, Experiments 1-A and 1-B could not be meaningfully compared in terms of display time. Although both horizontal and vertical motion occurred across the same amount of physical space (about 11 mm), more steps were required to scroll the bars vertically, which resulted in a longer display time and a slower rate of motion. Thus, neither rate of motion nor display time can be used to equate horizontal and vertical motion. However, horizontal and vertical motion can be directly compared using duration of the delay between successive frame onsets, i.e., SOA between frames. SOAs used in each condition were 5, 10, 15, 20, and 25 ms.

Procedure: Each subject rested his or her left index finger on the tactile matrix of the OPTACON. Amplitude of pin vibration was kept at a constant, comfortable level, which was maintained throughout the experiment. To reduce distractions and auditory cues produced by the vibrotactile matrix, subjects wore headphones delivering white noise. Trials were presented using a two-alternative forced choice procedure, and were self-paced.

In Experiment 1-A, four vertical bars were scrolled right-to-left or left-to-right across the width of the matrix in a "Times Square" mode. In each trial, three of the bars moved in the same direction; one bar always moved in the opposite direction of the other three. This "opposite motion" bar was systematically varied to appear in all temporal positions: first, second, third, and fourth. The stimuli were grouped into two pairs of two bars, with a temporal gap of 100 ms within pairs and 250 ms between pairs. Because of this grouping, one stimulus pair contained two bars moving in the same direction, whereas the other pair contained two bars moving in opposite directions. The subjects' task was to identify the pair of bars (first or second) that contained the opposite motion bar. Subjects pressed one of two pushbuttons on a switchbox to indicate responses. Direction of motion of the opposite bar was counterbalanced: in half the trials, three bars moved right and the opposite bar moved left; in the other half, three bars moved left and the opposite bar moved right. No trial-by-trial feedback was given. The format of the task in Experiment 1-B was identical with that in Experiment 1-A, except that horizontal bars scrolled up and down across the fingertip (i.e., along a different axis of motion).

Each subject received 50 repetitions of each of the 40 conditions for a total of 2000 trials in each part of Experiment 1. The order of presentation of conditions in each block was randomized (1 block = 80 trials). Experiments 1-A and 1-B were alternated every five blocks to compensate for any practice effects.

EXPERIMENT 2 METHOD

Subjects: Four sighted participants (one male, three female) with no formal OPTACON training served as observers in Experiments 2 and 3. Only the male participant served in Experiment 1 as well.

Stimuli: Stimuli consisted of 10 non-alphanumeric symbols, created to have no intrinsic semantic value to the observers (7); see Figure 1. When centered on the matrix, all symbols occupied a maximum width of 6 columns, and a maximum height of 18 rows.

Procedure: As in Experiment 1, the observers' task was to decide which pair of symbols contained the opposite-motion symbol. In Experiment 2-A, symbols scrolled left and right across the width of the display matrix (6 columns), and in Experiment 2-B, they scrolled up and down across the upper 18 rows of the matrix. Note that the increased scrolling distance in Experiment 2-B produced a longer display time at each SOA than in Experiment 1-B. SOAs were the same as in Experiment 1. The temporal gap between symbols was 200 ms, and between pairs of symbols was 350 ms.

Each subject received 52 presentations of each of 100 conditions, for a total of 5,200 trials in each part of Experiment 2. The order of presentation of conditions in each block (1 block = 400 trials) was randomized. Experiments 2-A and 2-B were also alternated every block.

EXPERIMENT 3 METHOD

Stimuli: In this experiment, stimuli were comprised of 10 alphabetic characters. Of these 10 letters, 5 were the least-confused letters presented via an OPTACON (6): *L*, *O*, *I*, *C*, and *U*. The remaining 5 were the most- confused letters: *Z*, *S*, *B*, *X*, and *G*. All letters were presented in upper case, in IBM standard Gothic sans-serif font.

When centered on the tactile matrix, all letters had a maximum height of 18 rows, and maximum width of 6 columns (except the letter *I*, which had a maximum width of 3 columns).

Procedure: Same as Experiment 2. In Experiment 3-A, symbols scrolled left and right; in Experiment 3-B, they scrolled up and down.

RESULTS

The longer the SOA between frames (i.e., the slower the motion), the greater the proportion of correct responses. These results are shown in Figure 2. In Experiment 1, three-way (SOA, axis of motion, and direction of opposite motion) repeated measures analysis of variance (ANOVA) was performed. Only SOA had a significant effect, $F$ (4, 60) = 41.5, $p < 0.001$. For Experiments 2 and 3, four-way (SOA, axis and direction of opposite motion, and symbols) ANOVAs were performed. Main effects of axis of motion were obtained in Experiment 2, $F$ (1, 600) = 652.72, $p < 0.001$, and in Experiment 3, $F$ (1, 600) = 533.62 $p < 0.001$. As expected, a main effect of SOA was found in Experiment 2, $F$ (4, 600) = 700.12, $p < 0.001$, and in Experiment 3, $F$ (4, 600) = 622.94, $p < 0.001$. Some letters in Experiment 3 were significantly more discriminable than others, $F$ (9, 600) = 2.72, $p < 0.01$.

Significant interactions were also obtained in Experiments 2 and 3. Axis x SOA was significant in both experiments: $F$ (4, 600) = 268.97, and $F$ (4, 600) = 350.18, both having $p < 0.001$. In Experiment 2, an axis x symbol interaction, $F$ (9, 600) = 3.85, $p < 0.001$, and an axis x direction interaction, $F$ (1, 600) = 8.96, $p < 0.01$, were obtained. Significant differences also existed between Experiments 1 and 3, and Experiments 1 and 2, $F$ (2, 1677) = 21.46, $p < 0.001$.

Post hoc comparisons were carried out using Scheffé's procedure with a = 0.05. Performance in Experiment 1 was significantly lower than in Experiments 2 and 3. In all three experiments, the two briefest SOAs were found to be significantly different from all other SOAs. In Fxperiment 2, the 15 ms SOA differed significantly from the longest SOA. Finally, in Experiment 3, the motion direction of letters *I* and *U* was found to be more discriminable than *C*, *G*, *Z*, *L*, and *X*.

DISCUSSION

The finding that no significant difference existed between Experiments 2 and 3 is likely due to subjects only having to make simple discriminations of stimulus direction, and not higher-order cognitive discriminations such as symbol or letter identification. This difference in tasks is likely responsible for the dissimilar results found in a previous letter-identification task (6). However, the similarities in results between direction discriminability and letter identification should not be dismissed. It may be that the characteristics of letters that affect their motion-direction discriminability also play a role in their identification.

In general, the results due to temporal manipulations are in agreement with those of Craig (3, 4), who used a letter-recognition task. The difficulty in discriminating motion direction at the briefer SOAs can be accounted for by temporal integration between stimulus frames. Evans (5) suggested that a tact stimulus creates a trace that is kept in a sensory store, ı om which it immediately begins to deteriorate. If a second stimulus is presented in close temporal contiguity with a preceding stimulus--such that the first trace has not sufficiently deteriorated--then the two traces will combine, effectively masking each other. In this study, each display frame is affected by forward and backward masking caused by the preceding and succeeding display frames, respectively. Craig (4) found evidence that temporal integration caused vibrotactile pattern masking. Also, temporal integration increased as SOA between patterns decreased (3), and almost total integration occurred at SOAs of less than 10 ms (4).

The data support the masking hypothesis. Performance increased with increasing SOA, suggesting that at longer SOAs masking has less of an effect on discrimination of motion direction. Whereas percent correct discriminations were at chance level at an SOA of 5 ms (except in Experiments 2-B and 3-B), they approached asymptote at 15 ms SOA (see Figure 2). Also, the greatest increase in performance occurred between 5 and 15 ms SOA.

Motion may be determined by comparing relative displacements of stimuli on the skin. For example, for a left-moving stimulus, the first pattern is succeeded by another one slightly to the left of it. The direction of motion may be inferred by comparing the relative displacements of successive frames. Evans (6) found that subjects could not determine the order of two events at brief SOAs, due to masking probably caused by temporal integration. Thus, at brief SOAs, errors in judgments of temporal order may cause errors in motion direction inferencing.

Experiments 2-B and 3-B produced greater discriminability of motion direction that cannot be accounted for in terms of SOA. The patterns scrolled across a greater distance and were presented for a longer display time in Experiments 2-B and 3-B than in Experiments 2-A and 3-A. By examining the results in terms of display time, however, these differences are diminished (see Figure 3). It is apparent that SOA alone cannot account for the results, but because display time is confounded with distance of motion, one cannot reach a conclusion regarding the basis of the increased motion direction discriminability in Experiments 2 and 3 (compared to Experiment 1).

The above findings have implications for sensory substitution in general, and tactile reading in particular. Future research in this area should identify the characteristics that make spatio-temporal tactile patterns such as letters more discriminable, and investigate how SOA interacts with display time and distance of motion, in order to determine the most efficient means of "reading" using the OPTACON.

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Karsten A. Loepelmann
Department of Psychology
P220 Biological Sciences Building
University of Alberta
Edmonton, Alberta, CANADA, T6G 2E9

Figure 1 Experiment 2 symbols

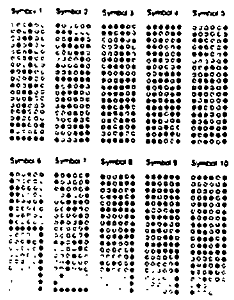


Figure 2. Discriminations of motion direction as a function of SOA.

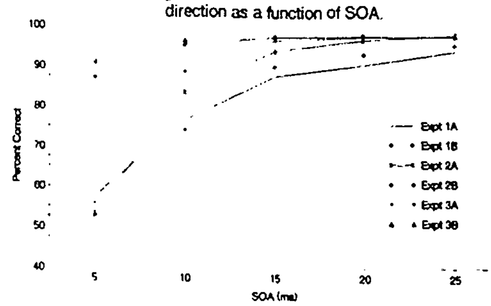
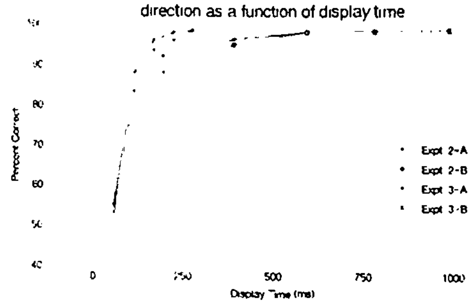



Figure 3 Discriminations of motion direction as a function of display time



# THE EARSIGHT PROJECT: MAPPING OF VISUAL SPACE INTO ITS 3D AUDIO ANALOGUE. A NEW BLIND AID

David A Boonzaier
Rehabilitation Technology Group
University of Cape Town & Groote Schuur Hospital
Medical School, 7925 Observatory, South Africa

**Abstract**

Some recent technological breakthroughs in mimicking the higher animal retina's ability to preprocess visual signals and the maturing of binaural (true 3D) sound imaging systems provide a unique opportunity window for a completely new device for helping the blind to "navigate" and advoid obstacles.

In the past there have been severe stumbling blocks in that blind aids were either narrow-field ranging systems, eg the ultrasonic cane - which required a large amount of purposeful and cognitively demanding manual scanning to "build-up a mental picture", (serial scanning) or otherwise 2D (vibro-tactile) representations with the implications of wide bandwidth (information-transfer rate) and the awesome problem of distinguishing features of interest from background noise in the face of poor spatial resolution. The inherent problem of how to transfer this large amount of information in parallel to the blind user remains unsolved, in spite of many years of research in 2D vibro-tactile, electrical surface stimulation, implanted micro-electrodes in the occipital (visual) cortex etc.

**New Technologies**

In publications in the last 2 years by the CALTECH LSI group under Carver Mead (see ref), has revealed a completely new approach to the problem of handling large amounts of real-world data in real-time. The imprecise-ness and/or uncertainty of these kind of data lend themselves to large-scale manipulations such as preprocessing: feature extraction, spatial and temporal filtering etc. In order to do these in anything like real-time precludes a digital approach. The technology - pioneered by Mead uses multi-layered LSI networked elements in an analogue computing solution to the problem. The connectivity of the particular analogue elements represents the hard-wired (programming) aspects which uniquely define the mode of operation of the network. One recent project, the subject of a PhD thesis by Misha Mahowald, uses just such an approach to mimicking the retina's architecture and function. The output of this "artificial retina" is not a large amount of visual 2D parallel data as one would expect from a simple CCD video camera) but rather a qualitative set of 3D reference points where "something of interest" exists. Features of interest may be: hard edges, eg a vertical bar of narrow width might represent a pole, a horizontal step change in brightness - the horizon: or more interestingly things moving relative to background may be either truly moving objects, eg another person - or otherwise inanimate objects appearing to move since they are nearer the moving "eye" (the so-called visual flow field).

This work constitutes a major breakthrough in the real-time data reduction/feature extraction problem which has bedevilled the artificial vision, (sometimes called robotic vision) field for many years.

Another more mature technology, pioneered by the NASA AMES group, (Foster, Fisher, Wenzel) and since commercialised as the CONVOLVATRON (see ref) is part of the explosion of auditory, visual, touchy and feely human interface devices which are entering the highly lucrative market of VIRTUAL REALITY systems. This new concept addresses the fact that a human user interacting with information technology devices is severely limited by the traditional interface, ie screen and keyboard. The multiplicity of human sensory and motor-output capabilities, provides a much richer experiential environment than current interfaces allow. The object of vitual reality research is to build a better mapping of the information space onto the users' perceptual and semantic world.

**The Challenge**

Totally blind people usually have all their other senses and it is the object of this rather ambitious project to use the redundancy in information - handling capacity of the blind to allow representation of their absent visual sensation by transforming it into the AUDITORY domain.

To clarify this idea, which for those of normal visual ability may be difficult to conceptualise, consider the notion of a blind person who enjoys going out into his garden when it is raining, to "listen to the garden" - not the rain. As you can imagine, the blind listener will "hear" each significant object - the garden shed, the pathway, the lawn differently - each in its precise place and with a particular "texture" or sound coloration peculiar to the nature of the surface, eg hard - the path or soft - the lawn.

**Methods**

The first phase of this project will be to allow congenitally blind children, as young as is practicable, to play in a highly structured interior space, with walls, chairs, tables, sofas, doors etc. Whilst experiencing the real sensations of 3D space: distance, position, size and texture to the touch, they will be given, via earphones, synthesized auditory ICONS of the same space, including the objects, which are produced by the convolvatron at the precise position and with particular sonic texture to help identify their situation, size, character and surface. The biggest challenge in this phase of the project is to choose suitable auditory ICONS ie outlines and fill-in sound-texturing to provide enough useful information to define position and to help identify the object.
Once this psycho-perceptual problem is solved we will be in a better position to use the information to design an automatic visual feature-extraction system which will provide the input to the auditory icon-texture generator.

The concept of "visualising" the shape and layout of a room by tapping a cane and/or listening to the natural echoes from sounds and speech is well-known (ref). Many blind people develop an uncanny ability to use this information - which, of course, is redundant to the sighted people (and is probably overlooked).

The resolution of the silicon artificial retina is at present a limitation, but seems to be only a problem of scaling (with cost-implications).

Preliminary results in the audio-representation field are encouraging and we do not foresee a problem in this area.

One remaining consideration is the lack of an overall direction-feedback mechanism for incorporating into the aid. It is possible that with the decrease in cost and increase in resolution of portable satellite-navigation-systems this technology may be added to allow blind users to have a constant reference for direction and position even when walking freely in open spaces.

**Conclusions and Future Considerations**

This is a very large project but can be attacked in chunks. Key researchers in the fields of:

* Silicon retina/LSI feature extraction

* Psychoperception of audio-imaging

* Virtual reality audio representation

have agreed to cooperate (ref). The coordiation of the project will be the responsibility of the author who is undertaking his sabbatical at Stanford University as from June 1992. Researchers interested in collaborating in this project should communicate with the author.

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Scott H Foster - Telepresence Research, Palo Alto, CA.

Scott Fisher - Telepresence Research, Palo Alto, CA.

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**Author's Address:**

Dr David Boonzaier
Director: Rehabilitation Engineering Programme
University of Cape Town Medical School
Observatory 7925
South Africa
Tel 027 (21) 4046117
Fax 027 (21) 4483291

10.1

# A Simple-To-Use Software Assessment Package for Testing Cursor Control Ability

Paul J. Schwartz and Karen L. Milchus
Center for Rehabilitation Technology
University of Wisconsin-Stout
Menomonie, WI

**ABSTRACT**

The effective use of a pointing device such as a mouse or trackball is important in operating a graphical user interface or computer aided design system. Presently, there are no low-cost software packages available to test pointing ability objectively.

This paper describes a software package that has been developed to test targeting, pointing, switch activation, and dragging ability. The program is simple to use for the client and evaluator. Time and accuracy data are recorded and available in detailed or summary form.

**INTRODUCTION**

There has been a dramatic increase in the use of graphical user interfaces (GUI) in many computer software environments. Low-cost computer aided design (CAD) systems are also increasing in use. These systems require effective use of a pointing device. The selection of an appropriate device may determine whether or not a GUI or CAD system can be used.

Pointing devices are often chosen using a subjective trial and error approach. Several researchers have tried to compare the operation of pointing devices (Baecker and Buxton, 1987; Dymond, Potter, and Griffiths, 1990). In addition, at least one IBM-based testing system has been demonstrated (Brownlow, et al., 1990). However, currently there is no system readily available to objectively assess the use of pointing devices for GUI or CAD applications.

We felt that such an assessment package would help evaluators make an objective choice of an appropriate pointing device. Quantifiable data may also assist in the specification of equipment to a funding agency. Given this need, a software package has been developed that tests pointing ability on various devices and records results for analysis and comparison.

**DESIGN OBJECTIVES**

- ♦ The test should quantitatively assess direct manipulation of a pointing device in terms of speed and accuracy.
- ♦ The test should operate similarly to an actual CAD application.
- ♦ The test should be able to compare a variety of input devices.
- ♦ The test should be easy for the evaluator and client to operate.
- ♦ The test should take a "reasonable" amount of time.
- ♦ The software should be affordable.
- ♦ The data should be available in summarized or detailed form.
- ♦ The test should have repeatable results.

**DESIGN**

A Macintosh-based system was chosen as the platform for the software. The Macintosh is commonly used in assessment, it is GUI based, and is a popular option for low-cost CAD packages. In addition, no Macintosh-based assessment software of this type has been developed. Finally, a user friendly software package is relatively simple to program on the Macintosh, keeping development cost comparatively low.

Three separate tasks were developed that test the skills required to use a CAD or GUI system: targeting, pointing-and-clicking, and dragging.

**Startup**

When loaded, the program displays a title screen and then provides a screen with prompts to record client and assessment information. The evaluator may choose the type of pointing device and the task(s) desired. All three tasks may be tested on the same trial. A practice session appears before each task.

**Targeting Task**

The test screen displays four similar targets in a square pattern. The client must position the cursor on the target indicated by an arrow and hold it there for 0.5 seconds. When a 0.5 second pause in movement is detected, the cursor position is recorded and the next target is indicated by the arrow. The process continues until the client moves around the square. The task begins with a large target approximately the size of a folder icon in the Macintosh system. After this is completed, the task is repeated using a smaller target, approximately the size of a mini-icon. The task is repeated a third time using a target approximately the size of the "pull-box" typically used in CAD programs.

**Pointing and Clicking Task**

The screen displays a pattern of five targets, each approximately the size of a pull-box, arranged in a square pattern with one target in the middle of the square, off-center, similar to that shown in Fig. 1. The client is required to move the cross-hair cursor to the target indicated by the arrow, then "click" to select that point. This is repeated for each target in a pattern that allows each direction (north, east, south, west, and the diagonal directions) to be tested. The length from beginning point to the target is the same for each move.

**Dragging Task**

The screen displays the five targets as in the point and click task, as shown in Fig. 1. The client is required to draw a line from one target to another, indicated by the words "begin" and "end". The process to draw is similar to that of a CAD package. The client must point the cursor at the desired starting point, click and hold the pointing device switch, "drag" to the "end" target, and release. With this accomplished, the start and finish indicators move on to the next set of targets, with the former "end" point becoming the new "begin" point. This is repeated in the same sequence as in the point and click test.

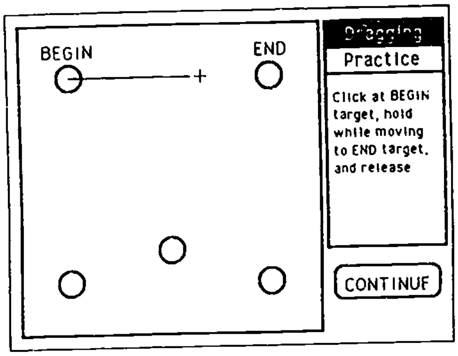


Figure 1. Practice Screen for the Dragging Task

**Data Collection**

Time and accuracy are recorded for each task. Time is measured in tenths of seconds and accuracy is based on a linear 0 to 100 scale. A cursor position directly on the target is scored as 100, and a cursor position further than 1/2" away from the target is scored as 0. Points falling within the 1/2" range are scored as a linear function of the distance from the target.

The targeting task records the time required to reach each target and the accuracy of the cursor position.

The pointing and clicking task records the time it takes to center over the desired target, the time required to "click" once the target is located, and the accuracy of the cursor position.

The dragging task measures the initial accuracy at switch activation, final accuracy upon deactivation, and the time required to move from the beginning to end point.

All data are saved in ASCII format for later analysis. The data are presented in a time and accuracy "composite" score for each task. If desired, the data are also shown in detailed form for analysis of where the difficulty may lie in each task, such as problems with specific directions or switch activation.

CONCLUSION

There are many factors involved in the assessment process that help an evaluator and client determine the best possible input device for a given application. Learning, comfort, cost/benefits and fatigue all may play a role in choosing a product. It is hoped that this simple-to-use software program will be a helpful item in any evaluators toolbox.

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ADDRESS

Paul Schwartz
Center for Rehab Technology
VRB 115, UW-Stout
Menomonie, WI 54751

# Assessment of Dysarthric Speech for Computer Control using Speech Recognition: Preliminary Results

Cheryl Goodenough-Trepagnier*, Harry S. Hochheiser*
Michael J. Rosen** & Hwa-Ping Chang**

* Dept. of Rehabilitation Medicine
Tufts University School of Medicine
Boston Massachusetts

**Dept. of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

## Abstract

As part of a project to develop an assessment and optimal design procedure for computer control by persons with neuromotor disabilities, a speech recognition assessment has been designed which captures speech data and allows it to be manipulated off-line. Analyses carried out with data from individuals with dysarthria (unclear speech) allow review of aspects of each individual's speech relevant to the project goal, including distinctness, accuracy, test-retest reliability over time, and relation to a clinical test of intelligibility. Results are presented for three individuals with dysarthria.

## Background

The goal of much augmentative communication and computer interface research has been to improve computer operation and communication rate. This project takes the approach that computerized speech recognition may be exploited as another control mode which can be integrated into the control strategies available to an individual with neuromotor disabilities. The background for this project has been described elsewhere (1).

The first stage of this project has been directed to development and testing of a speech recognition accuracy assessment for persons with dysarthria, unclear speech due to neuromotor disability.

## Research Questions

The primary research question of the project as a whole is whether and to what extent the evaluation and optimal design technique to be developed will improve the computer operation productivity of persons with neuromotor disabilities. The hypothesis underlying this question is that speech and motor control acts can be integrated in order to enrich the repertoire of strategies available to an individual for operating her/his computer. Testing this hypothesis requires a speech assessment which captures speech and makes it available for evaluation by the recognition device off-line, so that it can figure in the processing carried out by optimal design algorithms. Note that this approach to acquiring speech recognition data differs from standard practice, in which the individual is present, and his/her speech is submitted to the recognizer in real time, for matching against a single, specified set of templates previously created and stored in the device.

## Method

Participants in this study are individuals who identify themselves as having unclear speech and who are able to read the target words of the assessment vocabulary list. Prior to the assessment, each participant read a list of 50 words from the Beukelman-Yorkston dysarthria test (4). Each of these words is selected at random from its set of 12, and presented to the participant on the computer screen. The participant speaks the words into the microphone and they are tape recorded for evaluation by judges (two of the authors), who attempt to identify each word from the set of 12 of which it is a member. One purpose of this evaluation is to communicate our results more clearly by providing an independent measure of the severity of the dysarthria of the participants in the study. Characterizations of study participants by type and degree of dysarthria alone are inadequate for this purpose. The clinical measure also allows for comparison between intelligibility to human receivers and intelligibility in respect to the recognition device. Judge 1 (HH) was familiar with the participants' speech, while Judge 2 (CGT) was relatively unfamiliar with their speech. No participant spoke a regional dialect that was unfamiliar to either of the judges.

| | | | | | % correct word identification | |
|---|---|---|---|---|---|---|
| Code | Gender | Age | Educ. | Etiology | Judge 1 | Judge 2 |
| TM | M | 48 | 10 | TBI | 88 | 88 |
| JG | M | 43 | 14 | CP | 94 | 80 |
| LF | F | 36 | 17 | CP | 94 | 86 |
| BK* | M | 23 | 16 | NA | 96 | 94 |

**Table 1. Participants in the study**
*BK is an individual with typical speech whose scores are provided for reference.

The speech recognition system utilized was the DragonWriter 1000, an isolated-word, speaker-dependent, 1000-word vocabulary system installed in an IBM-compatible computer. An audio tape-recorder is also used. Speech is captured and stored by the Dragon system, and is simultaneously tape-recorded.

Data collection takes place using presentation software developed in the project. Each word is presented on the screen (in enlarged print), and when the participant is ready s/he pronounces the word. In case of a fluff (because of environmental noise, misreading of the word, coughs, extraneous speech) the captured material is deleted and re-presented.

The assessment word list contains 171 words, made up of 24 words. selected for their phonological properties, the 26 words of the military alphabet ("alpha", "baker", "charlie", etc.), the 10 digits, and 111 words which are typical computer operation words and synonyms for these words. The list is randomly divided into four subsets of roughly equal size, in order to allow for rest breaks after at least every 40 words. The data collection software presents the words for each subset in a randomized order, in order to avoid systematic order effects. Data collection could be interrupted for pauses at participants' request. Twelve productions of each target word were collected, over two to six sessions.

The fundamental units of speech recognition data for the DragonWriter system are *tokens* and *models*. A *token* is the internal representation used for a given speech sample, while a *model* is a template for a particular word, against which incoming speech samples are compared during the recognition process. The DragonWriter's software development library provides tools that allow for the creation of models from one or more tokens, and for the submission of tokens to be recognized against any existing set of models. During the *model-building* process, the recognition system can either accept a token or reject it as being unsuitable for inclusion in the model. During the *recognition* (identification) process, a token may be rejected (i.e., no identification is made) or confused (the wrong identification is made). Counts of rejections and confusions constitute the data for the analyses described below.

The design of the software and algorithm for selecting subsets of the vocabulary will be discussed elsewhere (2).

### Data analysis

Following are the conditions under which data were analyzed:

*All-to-all*: Models were constructed by submitting all 12 tokens for each word for the model-building process; recognition was carried out by offering the entire set of 12 x 171 tokens for each individual to the recognizer for identification in respect to these models.

*Some-to-others*: Models were constituted by submitting 6 randomly chosen tokens of the 12 collected for each word; the other 6 tokens for each word (those not offered to the modelling process) were then submitted to the recognizer for identification.

*Some(Time N)-to-others(Time M)*: This is a special case of *Some-to-others* described above: the tokens used for the model are not only different from the tokens submitted for recognition, they are also prior in time to the tested tokens. In the data described below, models were made from 6 tokens collected during the first half of data gathering, and testing was carried out using only tokens collected subsequently.

The data were analyzed in the following ways:

*Token rejection*: Percentage of tokens submitted which were rejected in the building of the model for each word, averaged across the entire list of words.

*Distinctness*: 100 minus average percentage confusion in recognition. The percentage of tokens confused for each word is averaged across the entire list of words, and this is subtracted from 100.

*Accuracy*: Percentage of tokens submitted for recognition which were identified correctly (i.e., neither confused or rejected), averaged across the entire list of words.

*Relative Information Transfer*: A metric based in information theory that evaluates speech recognition confusions in a manner that accounts for regularities in confusions, described in more detail in (3).

### Results

The following table presents results for the All-to-all condition (Table 2.), the Some-to-others condition with random selection of tokens (Table 3.) and the Some-to-others condition with tokens selected on the basis of time collected (Table 4.):

| | TM | JG | LF |
|---|---|---|---|
| Model-building (%) | | | |
| Token Rejections | 13.4 | 11.3 | 11.6 |
| Testing (%) | | | |
| Distinctness | 93.8 | 94.6 | 86.8 |
| Accuracy | 91.4 | 93.2 | 86.8 |
| Rel. Info. Trnsfr | 96 | 97 | 92 |

Table 2. All-to All: Models from 12, Testing of same 12

| | TM | JG | LF |
|---|---|---|---|
| **Model-building (%)** | | | |
| Token Rejections | 11.7 | 13.2 | 11.9 |
| **Testing (%)** | | | |
| Distinctness | 86.4 | 86.2 | 74.2 |
| Accuracy | 82.0 | 83.7 | 73.2 |
| Rel. Info. Trnsfr | 93 | 94 | 87 |

**Table 3. Some-to-some: Models from 6 selected at random, Testing of 6 others**

| | TM* | JG | LF |
|---|---|---|---|
| **Model-building (%)** | | | |
| Token Rejections | 12.0 | 10.9 | 10.5 |
| **Testing (%)** | | | |
| Distinctness | 85.4 | 83.8 | 72.4 |
| Accuracy | 81.4 | 81.4 | 72.5 |
| Rel. Info. Trsfr | 92 | 92 | 86 |

**Table 4. Some(Time 1)-to-some(Time 2): Models from tokens collected at Time 1, Testing of tokens selected at Time 2.**
*5 tokens tested

## Discussion

A comparison of the accuracy scores obtained when the same tokens utilized in the model are submitted for recognition (shown in Table 2.), with the accuracy scores for tokens different from those used in the model (shown in Table 3.) provide a representation of the variability in the speech of these individuals. Using accuracy in the All-to-all condition as a reference, accuracy in some-to-other conditions can be evaluated for the effect of number of tokens in the model. The purpose of this analysis is to determine how much "training" is required for each item by a particular individual in order for her/him to achieve acceptable accuracy. Data from additional individuals with more severe dysarthria and from individuals with typical speech, currently being collected, will allow us to assess the validity of the difference between all-to-all accuracy and accuracy when different tokens are used in modeling vs. testing.

The data reported above are all for the whole vocabulary set of 171 items. However the data capture and analysis technique described here makes it possible to examine the same data under different vocabulary subset conditions. Questions which can be investigated utilizing the collected data set include the effect on distinctness, accuracy and relative information transfer of factors of interest including word length (in number of syllables), consonant blends versus single consonants as syllable initials, amount of movement of the articulators (e.g., "cocoa" vs. "soggy"), phonological distinctiveness of members of set (how different the words are from each other) and number of words in the set. Particular points in time can also be compared, by constructing models and testing tokens from time periods of interest, e.g., pre, during and post for a course of medication.

The Time 1 versus Time 2 data presented in Table 4. above provide preliminary evidence of test-retest reliability of this assessment technique. Models constructed from the first half of the data collection yielded accuracy scores which differed only slightly from the scores obtained with random selection of tokens for models and testing with the residual tokens (shown in Table 3).

Optimal design of a speech recognition interface for persons with speech impairments requires an understanding of each individual's capabilities and preferences. By analyzing speech samples with the recognition system under a variety of testing conditions, it is hoped that the assessment protocol described above will aid in the design of speech recognition vocabularies that will provide the user with maximal utility and ease of use. The data presented above represent preliminary evidence that the protocol will be able to perform such a role.

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Cheryl Goodenough-Trepagnier
Associate Professor of Rehabilitation Medicine
Tufts University School of Medicine
750 Washington Street, 75KR
Boston MA 02111

# Determining Efficiency of User Assist Systems on Graphical Computers

Jeff Lewis, Randy Marsden and Steve Chrisafulli
Madenta Communications Inc.
Edmonton, Alberta Canada

Abstract

Many claims for the relative efficiency and productivity of various user interfaces currently circulate in the popular media and even the more scholarly journals, yet little statistical evidence of an objective nature exists to justify these claims. Further, as new user interface assists are developed with the goal of assisting motion limited users, the question of real improvement in efficiency and productivity become paramount - if a new assistance device or program actually hinders, it should not be promoted as being helpful.

At a simpler level, there is the question of selecting the appropriate solution for a given ability limitation in a more efficient manner and determining if a new solution under development is any better than existing solutions.[1; 2]

This paper discusses one attempt to collect and analyze meaningful data about how users interact with their computers and in specific, how they interact with keyboard and mouse replacements.

## Background

In all graphical user interface systems, the method by which the user interacts with the computer is the "event". Events, which can be thought of as a message sent from the operating system to a program, are caused when the user interacts with the computer's hardware or when some situation requiring the computer's attention occurs within the machine. Some events would be a key pressed down or released, the mouse button pressed or released or a disk being placed in a disk drive.

The core of a program written for graphical systems is what is commonly called an "event loop". This is a section of code which waits for incoming events. Typically, a program will wait until an event is posted (becomes available) for the program and may do other tasks while waiting. In current systems, a call to the operating system is regularly made to ask the system if an event is waiting. Next, the event is checked to see if it is an event which should be handled by the operating system and if not, then it is checked against a list of events which can be handled by the program.

Events which cannot be handled by the operating system or the program go unattended and eventually drop out of the queue.

Some systems, notably the Amiga and Windows, prevent certain events from reaching the program, preferring to let the operating system catch these before the program can see them. This makes the programs simpler, but makes writing code which intentionally intercepts the system information difficult.

## The Problem

Measuring efficiency or gains in productivity is difficult primarily because of the vagueness of these terms themselves. In the area of motion-limited user assistance on a graphical user interface based computer, one definition for improved efficiency and productivity would be that a system reduces the amount of time moving the mouse between "action" areas – places on the screen over which the user may want to place the mouse– or reduces the time spent typing in both the number of keystrokes and the time taken to type each stroke.

To that end, a system is required which can monitor the movements of the mouse pointer, the time between mouse button presses and where they occur, the time between keystrokes and the time between the depression of a key and its subsequent release.

One complicating factor is that the range of applications a user may choose to use and the widely varying natures of those applications makes analysis of collected data difficult and somewhat context sensitive.[3]

## Approach

The machine of choice for this project was the Macintosh computer. It allows the greatest access to the system through predefined mechanisms while still providing a high level of program support. Further, there exists very complete systems level documentation and a strong commitment to maintain a consistent interface for the programmer as well as the users. This ensures that specialised software such as that described herein, are not likely into interfere with other applications.[4]

A special class of program on this machine is called an "INIT" - a program which is run in very limited environs before anything else, including the primary user interface, has started. The program is given an opportunity to lock itself into place and take control of any system level operation. INITs do not have any user interface simply because when they are run, there is no user interface system running.

A companion program type is called a "cDev". This type of program often acts as a user interface for INITs.

Rather than trying to build one large program which does everything, the problem was divided into three components: data collection, control of the data collection program and data analysis.

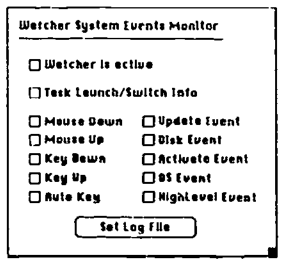


Figure 1 - The Control Panel

The first two would be combined into a "cDev" program which included an "INIT" program. On startup, the INIT would take insert a piece of code into the Macintosh's normal event posting systems. This code would catch every event generated by the system and write a copy of it to a file specified by the user via the cDev.

One of the events generated by the Macintosh operating system is the "null" event, used to give background programs time to do things. These events occur nearly continuously when the user is not actively interacting with the computer and would rapidly fill any storage device holding the history file. As a result of this, "null" events are not recorded.

Further, the user can select which types of events can be filtered out if less detail is preferred. A new holding file is generated on each startup to help partition the data into smaller, related blocks. Pleasesee Figure 1 on page 1 for an example of the types of events which may be filtered..

Once the data have been collected for a period, a second program is used to either translate the data into a format which can be used with more powerful statistical analysis programs or to do limited forms of analysis on the data.

Again, there is a problem of context related to the collected data. If the user is using a program which primarily text oriented, then monitoring mouse movement may be misleading. Conversely, a drawing program will rarely require keystrokes, so monitoring keystroke information will lead to erroneous conclusions.

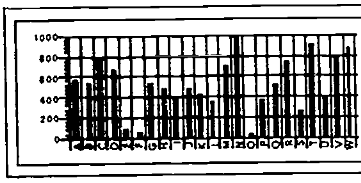


Figure 2 - Letter Frequency Chart

To solve this, every time a program is run, or becomes the foreground program, information about the program will be recorded in the history file. In this way, the person doing the analysis can selectively ignore events based on the program running during the period of the analysis.

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 607 | 942 | 890 | 617 | 31 | 219 | 687 | 681 | 360 | 112 |
| B | 104 | 516 | 636 | 22 | 200 | 957 | 327 | 556 | 180 | 759 |
| C | 869 | 773 | 203 | 304 | 361 | 216 | 181 | 363 | 869 | 521 |
| D | 517 | 470 | 618 | 415 | 408 | 936 | 210 | 441 | 307 | 194 |
| E | 688 | 310 | 821 | 971 | 818 | 671 | 799 | 441 | 872 | 675 |
| F | 476 | 862 | 195 | 610 | 370 | 543 | 947 | 189 | 259 | 79 |
| G | 880 | 123 | 96 | 857 | 378 | 789 | 497 | 509 | 535 | 822 |
| H | 623 | 728 | 813 | 300 | 115 | 5 | 918 | 460 | 912 | 805 |
| I | 915 | 911 | 524 | 331 | 140 | 201 | 32 | 933 | 388 | 198 |
| J | 709 | 262 | 688 | 198 | 408 | 886 | 607 | 550 | 389 | 925 |
| K | 645 | 144 | 918 | 440 | 686 | 68 | 297 | 816 | 269 | 752 |
| L | 681 | 236 | 584 | 853 | 285 | 959 | 535 | 271 | 253 | 233 |
| M | 3 | 600 | 401 | 285 | 926 | 858 | 41 | 820 | 629 | 895 |

Figure 3 - Two Letter Frequency

The other half of the system in a conversion/analysis program which allows the clinical or researcher to translate the raw event records into a format which can be used by commercial statistical analysis program such as MacSpin, DataDesk or SPSS, by a spreadsheet program for graphing. The built-in analysis provided by the system is fairly simple: single keystroke frequency(see Figure 2), keystroke pair frequencies (see Figure 3), keystroke pair time analysis, keystroke triples analysis (for detection of typical error correction modes), mouse down/up timing, mouse tracking and coordination (how many times did the user click then reposition and re-click) as well as visual replay of the mouse/click events to view the user's behaviour.

Discussion

The computer monitor described offers clinicians a way to objectively determine whether a specific computer access solution is actually aiding the subject or is simply changing the subject's behaviour without actually assisting.

It also provides a means to use a computer to detect certain functional disorders, such as dyslexia, by watching for character-delete-character triplets and monitoring the frequency of their occurrences(see Figure 4). It would also allow a clinician to detect more complex sequences of letter or letter group transpositions through more advanced statistical programs.

A possible index of cognitive delay may be found in the timing of key pairs or recognition timing as measured by recall/replay of key pairs.

Within the scope of the original reason for this program, to determine the efficiency and effectiveness of keyboard layouts, the test would consist of a standard text sample which skilled and unskilled operators would repeatedly enter over a period of days to determine which layouts are actually more efficient and which are quicker to learn. Combined with frequency/time analysis, it should be possible to fine tune a keyboard layout by reassigning positions and retrying the new layout interactively. This concept is not restricted to alphanumeric keyboards. Iconic keyboards and systems which use icons in a non-keyboard layout can also be monitored this way as long as the underlying

| Out | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 607 | 942 | 890 | 617 | 31 | 219 | 687 | 681 | 360 | 112 |
| B | 104 | 516 | 636 | 22 | 200 | 957 | 327 | 556 | 180 | 759 |
| C | 869 | 773 | 203 | 304 | 361 | 216 | 181 | 363 | 869 | 521 |
| D | 517 | 470 | 618 | 415 | 408 | 936 | 210 | 441 | 307 | 194 |
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| M | 3 | 600 | 401 | 285 | 926 | 858 | 41 | 820 | 629 | 895 |

Figure 4 - Letter/key/Letter Grid

code operates by passing events.

As well, this system is not limited to traditional pointing devices such as the mouse. On the Macintosh, all pointing devices interact through the event system and this ensures that any device which is position oriented (digitising tablet, trackball, eye-tracker) can interface to the Macintosh as if it were a mouse. The existing software base need not know about the special device, unless it wants to of course, and so we are given a way to uniformly record classes of actions rather than worrying about special hardware.

Other side-benefits of this monitor is that every keystroke and mouse action is recorded in the system's native format. By taking advantage of the Macintosh's journalling system, it would be possible to add feature which monitors the user's actions and typing and begin to provide adaptive, predictive assistance in much the same way that products such as ScreenDoors and Telepathic predict the next likely word as a user types and adapts the choices based on the user's word usage. This idea would lend itself well to the idea of assisting motion-limited users who wish or need to use a motion intensive interface like a graphical system.

It is conceivable that other assists may be derived from this product including reconstruction of entered data after a system failure, since every keystroke entered, including the error corrections, are faithfully recorded, by replaying the events back into the computer, the computer should be able to simulate the user and redo the lost work. A product which operates in just this way is already available on the commercial market. although it offers no statistical analysis.

*(Please note: numbers in figures are for purposes of illustration only and should not be construed as actual data.)*


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Jeff Lewis
Madenta Communications Inc.
Box 25, Advanced Technology Center
9650 20 Avenue
Edmonton, Alberta Canada

# THE EFFECTS OF COGNITIVE IMPAIRMENT ON PERFORMANCE WITH ASSISTIVE TECHNOLOGIES

Ned L. Kirsch, Ph.D., Simon P. Levine Ph.D., Heidi M. Horstmann, M.S.

Division of Rehabilitation Psychology and Neuropsychology; Rehabilitation Engineering Program
Department of Physical Medicine and Rehabilitation
University of Michigan

## Abstract

Assistive technology techniques can result in increased cognitive and perceptual requirements as their designs accommodate for increasing motor impairment. The impact of these requirements is especially significant for people who experience mental impairments such as those resulting from traumatic brain injury or disease. A review of cognitive and perceptual deficits specifically associated with traumatic brain injury is presented together with an analysis of the impact of such impairments on performance with assistive technologies. Approaches to assessment and training with assistive technologies for users with cognitive impairment are discussed.

## Background

People who sustain brain trauma or disease can experience a wide range of cognitive and/or perceptual impairments in addition to motor impairments which can directly affect their abilities to operate assistive technologies. These deficits can be classified into attention, orientation, memory, verbal reasoning and problem solving, perceptual/ analytic abilities, social reasoning, and executive abilities. Impairments in any of these areas can have a direct impact on performance with an assistive technology system.

## Problem Statement

An accompanying paper (1) discusses the cognitive and perceptual requirements for accessing assistive technologies. Support is presented there for the premise that in accommodating for increasing motor impairment, the design of an assistive technology usually results in increased cognitive and perceptual requirements being imposed upon the user. These increases in mental load can occur from the use of various assistive technology techniques such as scanning, encoding, proportional control, etc..

Increased cognitive and perceptual requirements have performance costs associated with them which may sometimes offset or even outweigh any physical efficiency gains obtained through various interface techniques (2,3). In the extreme case the mental requirements to operate an assistive technology system can even make it inaccessible to certain users. While this is an important issue for those with purely physical deficits, it is especially critical for people who additionally have mental impairment. This paper specifically focuses on the effects of cognitive and perceptual impairment on performance with assistive technologies.

## Approach

A brief review of cognitive and perceptual deficits associated with traumatic brain injury and disease follows which describes how they can affect general user performance. Examples are presented to illustrate the impact of such deficits on the use of assistive technologies. The emphasis of this paper will be on an analysis of performance with assistive technologies designed for individuals with either motor or combined motor and cognitive impairments. The concepts presented, however, should be readily generalized to technologies such as cognitive remediation software, activity guidance systems (4-6), or other approaches which are designed for people having primarily cognitive impairment with little or no motor involvement.

Attention. Attention is the ability to maintain cognitive effort, free from distraction or interference. There are three types of attentional skills which are typically affected by injury or disease: sustained attention, selective attention, and alternating attention . Sustained attention (or concentration) is the ability to maintain effortful and/or deliberate activity, free from distractibility. Selective attention is the ability to filter out irrelevant or competing influences in the environment. Alternating attention is the ability to shift rapidly between competing environmental stimuli or conceptual lines of thought. All of these skills are basic prerequisites for learning to use an assistive technology system and to develop skill with the system (e.g., to drive a power wheelchair independently and safely).

Some assistive technology systems, such as scanning interfaces, require the ability to respond in a rapid and timely fashion. This type of system is not likely to be successful with an individual whose attentional skills are significantly impaired because such deficits often produce delayed reaction time.

Orientation. Orientation, like attention, is a fundamental cognitive skill which represents the individual's appreciation of the passage of events and of self as an element of the environment. It too is a prerequisite to the purposeful, goal-directed behavior that is necessary to use an assistive technology system.

Memory. Memory is typically considered to be made up of multiple components which can be categorized in a number of ways. Deficits in any component of memory can impact an individual's ability to learn to use an assistive technology system, although it is often possible to compensate for mild deficits by supplying external aids such as a list of steps for common procedures. Memory deficits will also affect performance. For example, an individual who is entering a message into an augmentative communication system may forget what the message is before completing it, especially since completion of the message may take several minutes. Individuals whose memory deficits involve non-verbal or spatial information may have difficulty developing skilled use of a powered mobility system, as even frequented environments will always seem brand-new.

Verbal Reasoning and Problem Solving. Deficits in this area involve any skill area in which the manipulation and use of verbal concepts is required. For example, limitations with logical thinking and problem solving can severely impact an individual's ability to recover from simple errors while using an assistive technology system and will therefore limit the degree of independence that can be achieved with the system.

Limitations in understanding conceptual relationships (e.g., similarities, differences, category membership, analogical, or metaphorical relationships) impact an individual's ability to learn and use assistive technologies. This is particularly true with computer access and augmentative communication systems where encoding techniques which rely on verbal concepts require the user to recognize the relationship between an abbreviation and its expansion. Choice of such systems for an individual with difficulties in verbal relationships must be made with care, as they may present unnecessary or insurmountable learning barriers.

Difficulty with specific skills such as reading comprehension or vocabulary, including those unrelated to aphasia, have a clear impact on choice of system. Depending on the degree or nature of the deficit, it may be necessary to select a system that uses pictorial or other non-verbal forms of information in all aspects of interaction with the user.

Perceptual/Analytic Abilities. Perceptual/analytic abilities include non-verbal thinking skills which require a meaningful appreciation, interpretation, or manipulation of spatial and configural information about the environment, the body, or the body in relation to the environment. Perceptual/analytic deficits may be accompanied by, but are not synonymous with, sensory change. Deficits in this area may, for example, impact an individual's ability to maneuver a power wheelchair safely through the environment, as the individual's "map" (perception) of the spatial environment may be inadequate. As another example, deficits in this area might affect the ability to find and select characters or pictures from the display of an augmentative communication system.

Social Reasoning. Social reasoning skills are a complex set of abilities which are necessary for effective interpersonal relationships. While the specific definition of these skills varies from culture to culture, they generally include: the ability to recognize and/or engage in socially appropriate behavior in common situations; the ability to see things from another person's point of view; sensitivity to another's emotional expression; and the ability to respond differently to particular social behaviors based upon the context in which they have occurred. These skills are important for the operation of many assistive technologies. For example, they provide the basis for linguistic pragmatics, and as such are necessary for fully effective use of an augmentative communication system. Social reasoning also impacts performance with powered mobility systems, providing a way for the individual to judge, for example, when driving very close to another person is fun and when it is dangerous or annoying.

Executive Abilities. Executive cognitive abilities are those which permit effective adaptation and accommodation to changing environmental demands through the appropriate and efficient integration of more basic cognitive skills. These skills include: flexibility of thinking; the abilities to plan, organize and form strategies for problem solving; and self-monitoring and self regulation. A minimum competency in these skills is necessary for an individual to understand what assistive technology is and decide whether it is a desirable intervention. Advanced levels of executive abilities are necessary to effectively use many assistive technology systems. For example, environmental control systems may be programmed to perform certain home control tasks automatically, but for an individual to use this feature effectively, he/she must be able to first develop an overall strategy for how appliances, lights, and thermostats should be manipulated over the course of a day. As a second example, some powered mobility systems provide a power recline feature that allows the individual to independently provide pressure relief. For this to be beneficial, the individual must have sufficient self-discipline and self-monitoring ability. Without these abilities, the presence of the system could actually be harmful to the individual, since care givers may assume that they need not assist with pressure relief.

### Implications

Many people with cognitive impairment also experience a physical disability. These individuals often have needs which can potentially be satisfied through the use of an assistive technology system. However, many such systems are primarily designed for people with physical disabilities and may include (optional or mandatory) techniques or procedures that are inappropriate for a user with mental impairment. Therefore, proper knowledge and understanding of a potential user's cognitive and perceptual impairments is critical since they can have substantial impact on the level of performance with an assistive technology or even the basic ability to utilize such systems at all.

There are trade-offs involved in using assistive technologies which result from the fact that cognitive and perceptual requirements of a system typically increase as the design accommodates for decreased motor skills or aims at reduced physical effort to improve performance. These trade-offs complicate the assessment process. Further difficulty in evaluation occurs when learning impairments are involved, since a substantial amount of user experience and learning may be required before performance can be adequately assessed.

In some instances, a learning impairment may necessitate the temporary employment of an assistive technology whose use can be discontinued following appropriate performance gains. As a simple example, consider the hypothetical case of a person with a traumatic brain injury and a subsequent learning impairment. In learning to type, it might take an extremely long time for such a person to learn the positions of the keys for effective text entry. Thus, a computer based word prediction system might enhance performance and provide positive feedback for motivating the user to continue using the system. If, however, the user's keyboard input rate increased sufficiently over time, then word prediction might become less efficient or even detrimental to overall performance (2).

### Discussion

In cases where users have deficits in areas of cognition which appear to prohibit the use of an assistive technology, a number of options are available. For some people with cognitive impairment it may be possible to increase task complexity in stages as mastery of each successive stage is achieved. For example, the relatively complex strategy required to select a row, then column, from a two-dimensional scanning matrix can be acquired by training the user with a simpler one-dimensional scanning array. It may then be possible for an individual to progress to a simple two dimensional array with a reduced set of options, and then gradually on to the entire matrix. Other individuals may be able to learn specific compensatory techniques which permit them to use assistive technology systems, despite deficits which do not improve over time. For example, individuals whose memory problems prevent them from keeping track of messages or their current level while working with a communication system, may be helped by learning to rely on cuing systems that guide them during various phases of a task (e.g., inserting a field in a communication system display which always presents and highlights the current level). Finally, for those who have deficits which persist and do not respond to compensation or remediation, it may be necessary to modify the task demands so that they conform to the patient's skill level.

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### Address

Simon P. Levine, Ph.D.
Rehabilitation Engineering Program
1C335 University of Michigan Hospital
Ann Arbor, Michigan 48109-0032

10.5

# ADAPTING THE MACINTOSH TO BECOME A FLEXIBLE LIVING AND WORK AID

Randy Marsden, P.Eng.
Greg McGillis, B.Sc. E.E.
Murray Hensch, Engineering Student, C.E.T.
Madenta Communications Inc. (Edmonton, Canada)

## Abstract

This paper describes a computer based system which can provide people with disabilities the ability to communicate effectively and become more independent. This system can also provide vocational opportunities. The heart of this system is an Apple Macintosh™ computer; one computer can be used to control lights, appliances, door openers, an intercom, a telephone, and infrared devices, as well as provide capability to access existing applications.

## Background

The computer has proven to be essential in integrating people with disabilities into the mainstream work place. These machines, properly adapted, can help people who are physically challenged to be much more independent by enabling them to control their surroundings and communicate more effectively. Further, they can help level the playing field for thousands of people whose minds and skills are still very valuable commodities in today's working world.

## Statement of the Problem

The problem involves two main areas:

First, people with disabilities require greater power to interact in and control their environment. This increased interaction includes the ability to acquire information as well as control devices in a person's environment. Some of the devices to be controlled are: the telephone, ac lights and appliances, intercoms, door openers, television, and other devices that may be specific to a particular person.

Second, their opportunities for meaningful employment need to be increased. This may involve a vocation based on the ability to access computer programs (e.g. database user/programmer), or based on the ability to use a computer as a tool to control other devices.

## Approach

The discussion of the solutions for the two problem areas, identified above, have been divided into four categories: Computer Access, Environmental Control, Infrared Control, Telephone Access, and Voice Communication.

*Computer Access*

Headpointing computer input devices are available which enable disabled persons, through head movement, to execute computer functions normally performed with a single button mouse; the single button mouse is an integral device required for access to Macintosh computers. This device is worn on the head, and facilitates cursor movement by the user moving his/her head; thus the cursor follows head movements just as it would follow mouse movements. Two examples of headpointing devices are: HeadMaster, manufactured by Prentke Romich Company, and FreeWheel, manufactured by Pointer Systems.

Some people with disabilities are adept at using a mouthstick for a variety of tasks. Adapted mouthsticks can be used to access computer keyboards and computer disks. But, mouthstick keyboard access may have speed limitations and may be cumbersome; the requirement to always look down at the keyboard can be distracting. A better solution, called an "on-screen" keyboard, is available.

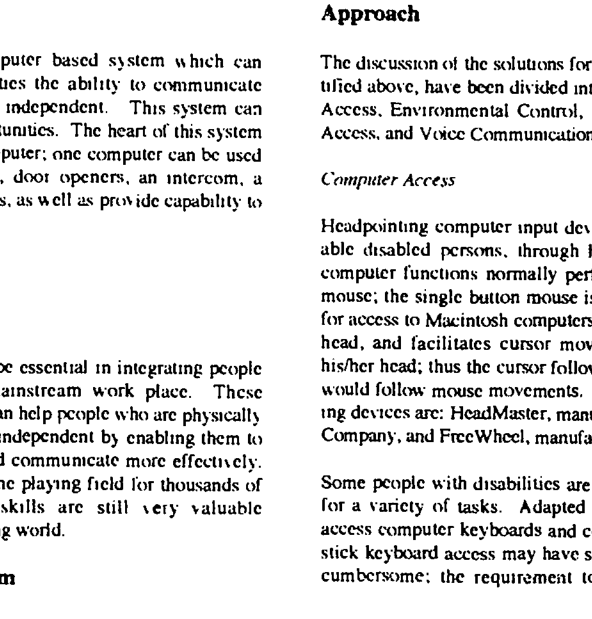

Figure 1: The Macintosh System

An on-screen keyboard, called ScreenDoors™, is manufactured by Madenta Communications Inc. This resizeable keyboard looks like a normal physical keyboard, but appears on the screen. By simply pointing and clicking on the desired key, the key selection is executed (e.g. a letter is typed just as it would be from a normal keyboard). The combination of HeadMaster and ScreenDoors can offer complete and efficient control of the Macintosh.

Another access method which is available is voice control. An existing device called Voice Navigator™, which is manufactured by Articulate Systems Inc., can be used to convert spoken command into computer commands for control of computer applications. Thus, computer functions normally performed with a keyboard or mouse can be accessed through spoken commands.

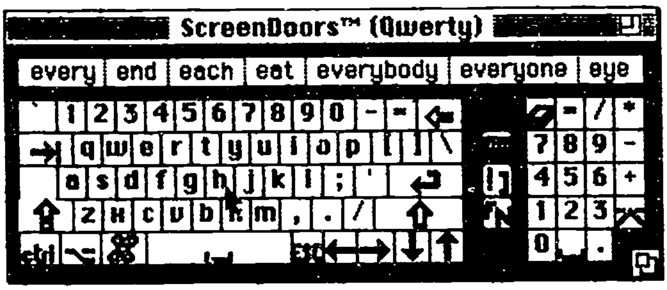


Figure 2: An On-Screen Keyboard (ScreenDoors™)

Equipment controlled by spoken commands can be accessed remotely through a bidirectional wireless audio link. This allows disabled persons freedom to move throughout a specified area while maintaining voice contact with a particular central control location. Voice access can be accomplished by the user speaking commands into a lapel microphone and listening to either a privacy speaker or peripheral amplified speaker, both of which can be attached to a wheelchair. This feature provides ability to give a spoken command to the computer from virtually anywhere in or around home.

*Environmental Control*

Many people with disabilities are unable to control various devices within a home, particularly ac powered devices, such as lights, fans, and appliances. This control can be accomplished through the use of an "X-10" controller which sends control signals to modules through existing household wiring. Each module, which is situated at the location of a device being controlled, responds to its particular control signal by turning on/off, or adjusting intensity of the device. These modules can be used to control virtually any ac device.

An X-10 controller and software designed for the Macintosh allow the user to control the modules from the screen of the computer. Also, voice commands may be assigned to the X-10 computer functions using Voice Navigator.

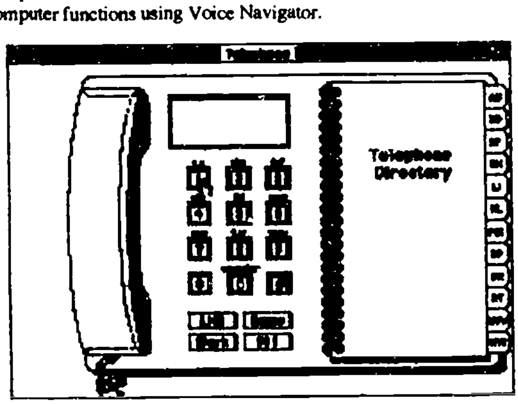


Figure 3: Telephone Access

*Infrared Control*

A method of accessing infrared controlled devices, such as TV, VCR, and CD players can be beneficial to people with disabilities. Universal infrared remote control devices are available for interfacing to computers, and custom software enables computer control. Again, voice commands could be assigned to various remote control functions.

*Telephone Access*

Telephone access can be an effective communication medium for both personal and vocational applications. For people with disabilities, this access is available through telephone interface hardware included in one of the Voice Navigator products. Custom software provides access to this interface through a computer, as well as access to common telephone features, such as dialing pre-stored numbers available in an on-screen telephone directory, last number redial, link and hold can be provided. As with other devices discussed, the telephone may be accessed through voice commands.

*Communication*

Many people with disabilities are unable to respond to callers at an outside door/entrance, in addition to inability to communicate effectively with people who are in a separate room. An in-house intercom system can provide this capability. Control of an intercom can be achieved through custom hardware and software which provide the necessary access to "talk" and "listen" buttons. Also, voice commands may be used to control the intercom.

## Implications

This paper has indicated that through the use of custom software and readily available third party products for the Macintosh, a complete system providing home control and greater independence can be assembled. Therefore, this type of integrated solution can be an attractive alternative to dedicated home control systems; there are the added advantages of expandability, flexibility and enhanced functionality.

## Discussion

Not all of the possible input methods have been discussed in this paper. Other methods are available which provide general access for people spanning a large spectrum of types of disabilities, such as adapted direct keyboard access methods and scanning solutions for single switch users. Regardless of the form of access, all solutions discussed in this paper may be employed to the benefit of those people with disabilities requiring greater independence and enhanced quality of life.

At the time of writing of this paper some work remained in the design and construction of the components comprising the system described, though it is expected all development will have been completed by the time this paper is published. Further analysis and evaluation of this system will proceed upon completion.

**Randy Marsden, P.Eng., Madenta Communications Inc, Box 25, Advanced Technology Center, 9650-20 Avenue, Edmonton, Alberta, Canada T6N 1G1, (403) 450-8926.**

## 10.6 PROSTHETIC SOFTWARE FOR INDIVIDUALS WITH MILD TRAUMATIC BRAIN INJURY: A CASE STUDY OF CLIENT AND THERAPIST)


Elliot Cole, Ph.D.
Parto Dehdashti, Ph.D.
Institute for Cognitive Prosthetics



### ABSTRACT

A year long case study explored the use of computer software as a prosthesis for a high functioning traumatic brain injury survivor. A substantial amount of customization to the software interface was required, and was attributed to user cognitive deficits. The software was able to restore functioning which had not been accomplished using manual techniques. Impact on therapy and therapist are described.


### BACKGROUND

Previous work with cognitive prosthetic computer software focused on needs of individuals who required supervision in their daily lives (Cole and Dehdashti, 1990A). That work found that software could be effectively used for both relatively unstructured household and leisure activities, as well as well-structured activities, consistent with the work of Kirsch and Levine (1987) and of Steele (1989). It was found that the software interface was a primary barrier to use of commercial software. Our study applied theory from the computer science areas of human computer interaction and office automation, relating to increasing individual cognitive productivity. Anecdotes from TBI survivors and family members indicated that the computer interface was an insurmountable barrier to individuals who had successfully reentered the community. Some had intellectually demanding vocations. These are high functioning survivors above Rancho Los Amigos Level VIII

The present study examines uses of cognitive prosthetics for individuals classified as high functioning, but whose deficits do not allow them to function at their pre-morbid level. However, these people can live independently, i.e., do not need a caregiver or companion to help them perform household or vocational tasks.

### OBJECTIVE

This study extends the previous study in two major ways. First, the research addresses a high functioning population. Second, the study begins to explore the ways this technology changes the process of cognitive remediation therapy, and impact on the therapist. Specific research objectives were to:

1) identify the types of modifications to computer interface and application required for high functioning adult TBI survivors

2) identify the therapeutic impact of cognitive prosthetic software for these individuals, and

3) examine some of the needs of the therapist using this innovation.

### METHOD

This is a single-subject case study, a methodology frequently used with traumatic brain injury subjects. A field study design was used to achieve the research objectives requiring substantial computer usage over time, and for activities which are relevant to the conduct of the subject's life. Data included observation of weekly therapy sessions, medical chart, computer state transition logs, and software specifications for interface and underlying application. A quasi-experiment was selected, and therapy sessions were observed for one month prior to the intervention. Interface design and testing sessions were incorporated into the therapy sessions. Interface performance was measured by training time and ability to understand commands and instructions. The software was used only during therapy sessions for two months. Then the computer system was introduced into the subject's home in April 1991. Data collection is still in progress as of this writing (January 1992).

The subject is a 40 year old college-educated male, 7 years post injury. On the surface, he had successfully returned to the community because he had lived independently, worked at a supervisory job, and managed his household affairs, and he had no physical impairments. Furthermore, he masked his cognitive deficits quite successfully. He would forego parts of activities which were beyond him, rather than ask other people for assistance in carrying out the activity. In this way, his masking behavior successfully hid the impact of his deficits on vocational, household, and leisure activities.

Neuropsychological testing found diffuse cerebral dysfunction, with deficits in memory, attention and concentration, reduced mental processing time, reasoning and problem solving, and functional integration. He had been receiving cognitive remediation therapy for 11 months prior being referred for cognitive prosthetic intervention.

Two applications were introduced, a basic text editor and a weekly calendar/appointment reminder

### RESULTS

Results are presented in three sections.

Interface and application customization

The subject had substantial difficulty forming an accurate mental model of the commands, but was able to understand the overall objectives of the applications. Text editor commands were implemented on bounce bar menus, which reduces the memory burden on the user. The software interface required substantial modification, particularly the command text which used the patient's phraseology. Even minor changes in command text had a substantial impact on interface comprehension and performance. Some of the text modification forced changes in the size of interface objects (boxes) containing the text. Document names were 60 characters to allow ample room for description; even so, the user requested time stamp information on the document retrieval menu.

The second application is a combination of personal scheduler and "To Do" list. A combination of interface styles were used: soft function-key, bounce-bar sub-menu, and fill-in-the-form (for the actual appointment). In this interface also, most of the modifications involved rephrasing commands and instructions so that they could be correctly understood. The calendar provides additional memory support, so the patient can provide himself with reminders and instructions for specific events or appointments.

Prosthetic Uses of Software

The prosthetic software has improved the patient's level of functioning in a number of areas. Perhaps the most dramatic change was in the area of reasoning and problem solving. The software provided him with a medium which supports a non-linear processing style: he is able to move from one facet of the problem to another. It also helps maintain focus on the dimensions of a problem, without loosing track. Problem solving and reasoning is substantially improved because of the complexity he is able to incorporate.

There were immediate improvements in the patient's ability to organize, attend to, and complete tasks during therapy sessions. (These tasks involved a job search). Using paper and pencil methods, he would work for 10 to 15 minutes, and the stop with the work unfinished Using prosthetic software, he could work for 30 - 45 minutes continuously, as well as complete the activity. The therapist reported that before she had to introduce an activity in one session, and work at completing it in the next. From the patient's perspective, the process of using the prosthetic system allowed him to "concentrate on a specific item, rather the on a complicated web of problems."

The computer significantly improved the patient's ability to track and monitor projects. Before, information was stored in a loose-leaf notebook, where information could not be easily located. In the area of communication, he began writing brief letters to friends with whom he had not corresponded in a long time

The calendar application has been implemented only with limited functonality thus far It helps track appointments and activities The software enhancement allows extensive reminders to accompany appointment entries, and this feature has been useful for its memory support. A functional enhancement will link project monitoring to the scheduler.

In addition, the status-enhancing nature of computer use raised his self-esteem.

Impact on Therapist and Therapy Methods

Several effects on therapy and therapists have emerged thus far. First, the therapist has had to learn new skills in order to use prosthetic software. Some of these skills related to learning how to train patients in computer mechanics, and some skills involve therapeutic use of the software. Second, the data collected by the software allows the therapist to track the patient's computer usage in considerable detail. This data is used in planning therapy sessions as well as monitoring patient progress. The data provides clues to situations arising in the patient's life. Third, the preparation time for therapy sessions has increased, as result of the availability of progress data. Fourth, the patient has been able to continue work on tasks which began during therapy sessions. And fifth, the clinician has been able to better assist the patient in-between scheduled therapy sessions.

## DISCUSSION

The results of this study show point to three issues. First, and most important, that properly designed computer software can help restore function in brain injury survivors with mild deficits. Second, that the software interface can be a major barrier to successful computer use. and third, use of appropriately designed software can help restor functioning to a high functioning brain injury survivor. It was not expected that high functioning survivors would have continue to have disabilities which continued to interfere with their functioning in the community.

Furthermore, it was not anticipated that such a person would have substantial difficulty learning how to use novice-oriented software. Indeed, we had assumed that interface customization would be appropriate only for moderate to severely disabled survivors. However, after meeting a number of individuals at support group meetings, we began to question the assumption. Several of these individuals were college students who were unable to use any of the word processors available from campus support services for people with disabilities. (Recent studies by Glisky (1991) and Prevey et al (1991) demonstrate that even severe amnestics can be taught to use computer software, given enough time -- months and possibly years -- and specialized training.)

Computer software has been shown to be a successful orthotic for relatively structured activities (Kirsch and Levine, 1987; Cole and Dehdashti, 1990). This case study has shown how software can be used as an orthotic or prosthetic in relatively unstructured activities such as reasoning and problem solving.

Computer software is not currently viewed by the rehabilitation community as a compensatory strategy

Software is and can be a powerful compensatory strategy, capable of restoring function when other techniques cannot. However, many 'superior technologies' have failed at technology transfer stage because of institutional factors. Among these factors are the structure of the therapy session and the impact on the therapist. These are not insurmountable barriers, but they do need to be addressed.

This is our second case study, and involves scores of hours of working directly with patient and clinician over the past year, as well as hundreds of hours modifying computer software. The case study methodology provides a detailed understanding of a problem in a field where mastering the details are critical to success. By the Annual Conference, we will be able to report preliminary findings on three additional patients who are part of a research project funded by NIH.

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**Author's Address:**

Elliot Cole, Ph.D.
Institute for Cognitive Prosthetics
146 Montgomery Avenue
Bala Cynwyd PA 19004
Tel: (215) 664-3585
Fax: (215) 664-6201
email: cole@wharton.upenn.edu

# CHEC-RITE: A PORTABLE CHECKBOOK MANAGEMENT DEVICE FOR INDIVIDUALS WITH MENTAL RETARDATION

Daniel K. Davies, Randy W. Dipner, and Robert H. Gattis, Jr.

Meeting the Challenge, Inc.
Colorado Springs, CO

## ABSTRACT

This paper describes Chec-Rite, a system for improving management of personal checking accounts for individuals with mental retardation. This project is an SBIR Phase 1 project supported by the Department of Education. The Phase 1 research plan focused on establishing the technical merit and feasibility of the automated checkbook management system. An initial "proof of concept" software-based design prototype was developed for testing with individuals with mental retardation. The product concept has been designed according to human factors guidelines to meet the specialized needs of the user population. The system has applications with individuals with mental retardation, the elderly, and individuals with limited motor ability of the dominant hand. Progress to date is described as well as directions for future research and development.

## BACKGROUND

Research on ten community "survival" skills critical for adults with mental retardation were reviewed and analyzed by Martin, Rusch, and Heal (1). This study identified money management as one of the key "survival" skills necessary for individuals with mental retardation. Problems resulting from the inability to manage money have included cash-flow difficulties and uncontrolled debt for adults with mental retardation living in community settings (2). Martin, Rusch, and Heal summarized that simple money management skills can be acquired by individuals with mental retardation. However, future research is needed to determine whether individuals with mental retardation can master more complex money management skills including check writing and checkbook balancing.

Langone and Burton (3) report that skills required to successfully shop in retail establishments go beyond basic handling skills. These more complex skills may require adaptive aids that can allow individuals with mental retardation to bypass these deficits. Future research on the applicability of computer technology to enable the acquisition of specific living skills is necessary. Finally, Martin, Rusch, and Heal (2) stated that as more severely disabled individuals enter non-sheltered community settings, "prosthetic" means for money transactions must be developed to serve these individuals. Accordingly, the Chec-Rite system applies computer technology to simplify the complex money management skills of checkbook balancing and check writing.

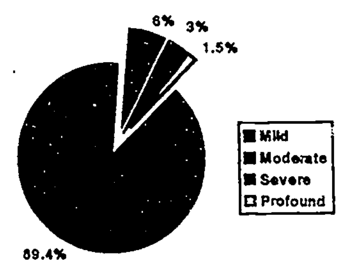
## PROBLEM IDENTIFICATION

Independent living for individuals with mental retardation depends on many factors including, but not limited to, the extent of the retardation and the effectiveness of teaching skills necessary for independent living. Money management is one of the most difficult skills for individuals with mental retardation to master, and attainment of the skill is key to independent living.

### *Significance*

While exact figures vary there is little doubt that the U.S. population of individuals with mental retardation is in excess of two million. A National Institute on Disability Research and Rehabilitation (NIDRR) report estimates that approximately 1% to 3% of the population have mental retardation, i.e. IQ below 70 (4). In addition, it is estimated that there are an additional 2.5 million individuals who are considered borderline or low normal IQ. There are four levels of mental retardation ranging from severe to mild (5). Figure 1 depicts the percentage breakdown for each of the four levels of retardation.

**Figure 1: Percentage Breakdown of Mental Retardation Levels**




Clearly, the number of people with mental retardation is significant. Research focused on increasing independence for this group, thus, is of significant importance to the mental health community.

### *Independent living for individuals with mental retardation*

The possibility for independent living varies greatly for individuals with mental retardation depending upon the level of impairment. Highest functioning adults with mental retardation (IQ between 51 and 70) are most likely to achieve this goal as compared to more severe levels of impairment. This is encouraging considering that mild mental retardation accounts for 89.4% of those with mental retardation (4). Increasing numbers of individuals with profound mental retardation are also now living in community settings. The 1987 National Medical Expenditure Survey estimates that there are approximately 16,000 people with profound retardation living in small (15 or fewer residents) community care facilities (6). Innovative programs for individuals with mental retardation are increasing the likelihood that some level of independent living will be achieved. Greater independence corresponds to reduced service provider to client ratios, thus translating directly to cost savings. Independent living, therefore, remains one of the primary objectives of service to individuals with mental retardation both for quality of life and economic reasons.

*Skills required for independent living*

The ability to live independently requires acquisition of a variety of skills including, but not limited to, personal hygiene, cooking, use of public transportation systems, the ability to earn sufficient money to live, and personal financial management. Often, activities that are routine or even mundane to individuals with no developmental disability are extremely challenging for individuals with mental retardation. For example, identifying correct change for the bus can be a monumental task requiring tremendous effort. Failure to perform the skill correctly in the community setting can be a very frustrating and frightening experience. In addition, inability to perform basic living skills, such as money management, can be a crucial factor for not achieving greater independence. Therefore, all resources available to help train individuals with mental retardation must be utilized. Innovative technology can automate complex tasks and thus simplify some of the activities required for successful independent living. Automation and effective training techniques, e.g. computer-simulation (7), are both ways of using technology to increase the opportunity for individuals with mental retardation to learn key skills necessary to reach ever-increasing levels of residential independence.

*Automation: An alternative for financial management*

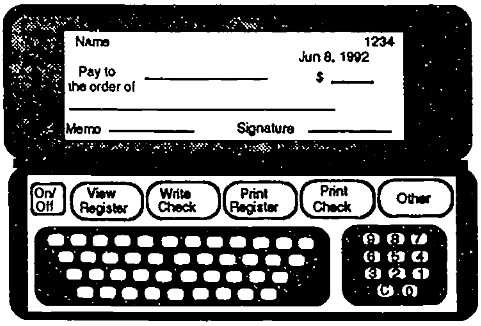
The extensive time and effort required by service providers to aid individuals with mental retardation in basic living skills, such as management of personal checking accounts, can be very costly to the mental health system. For example, the State of Colorado's 1990 rates for individuals with mental retardation vary according to the level of independence that has been achieved. Rates range from $83.08 per day for individuals with minimal independence down to $24.96 per day for individuals in community transition programs. Therefore, State supported costs of care decrease as greater independence is achieved. In some cases, cognitive limitations hinder the ability of individuals with mental retardation to acquire the full spectrum of skills necessary for financial management, e.g. addition and subtraction, and thus achieve greater independence.

High costs have limited acquisition of computer equipment for community care facilities. However, decreasing costs of personal computers in the past decade have brought technology more within reach. Monitoring the checkbook of individuals with mental retardation is a task often performed by a mental health practitioner, e.g. counselor, case manager, or living skills instructor. Computer technology provides an attractive alternative to continuous client monitoring by the service provider by reducing the complicated task of financial checkbook management to a limited set of skills that can be more easily mastered. Monitoring financial assets of clients can thus become less time-consuming and possibly even a much less frequent necessity. An automated system can help ensure, for example, that bad checks are not written or that no more than an allotted amount of money is spent during a given time period. In addition, common payee's, e.g. rent, phone bill, can be stored in the computer and accessed with just a few keystrokes. All these features can equip individuals with mental retardation with critical money management capabilities. Other personal computer check writing and account balancing programs exist. However, these programs have not been designed specifically for use by individuals with mental retardation, and they are not portable. In addition, these programs require the availability of a general purpose computer. The Chec-Rite system is envisioned to require no additional computer hardware or software.

## DESIGN AND DEVELOPMENT

Chec-Rite is a portable computerized device approximately 4" x 8" when closed. Power is provided either by batteries or an AC adapter. When opened, there is a keyboard with dedicated function keys on the lower half of the device and a liquid crystal display (LCD) screen on the upper half. Figure 1 depicts the device concept.

**Figure 1: Chec-Rite Design Concept Diagram**




Research is ongoing to identify the optimal user interface and functional capabilities to meet the specific needs of the target population. An initial design prototype has been developed on an IBM compatible computer as a Microsoft Windows 3.0 application. To increase operational fidelity a touch screen has been incorporated into the Chec-Rite prototype. This approach simplifies operation of the prototype and provides a more realistic assessment of the user interface.

*Chec-Rite design features*

Requirements for the Chec-Rite system have been categorized into *user requirements* and *case management requirements*. User requirements include basic system capabilities that must be available to the user with mental retardation. Some of these features include:

- capability to store/ retrieve common payees
- capability to print onto standard personal checks
- automatic addition/ subtraction
- automatic recording of checks written in register
- portability
- durability

Case management requirements are design features identified through field interviews with living skills instructors working with individuals with mental retardation on financial management skills. Features include:

- preventing checks which exceed current balance
- automatic reminders to write checks (e.g. rent)
- real-time budget/ check amount comparisons
- customizable check writing limits

*Status of development*

The Chec-Rite product is currently under development through the Department of Education's SBIR program. The Phase I research is scheduled for completion March 1992. An initial version of the Chec-Rite software suitable for use on a home computer is expected for release in the second half of 1992.

The second phase of the SBIR is anticipated to begin late 1992. Continuing research includes further design, development, and testing of the Chec-Rite system for commercial application to the population of individuals with mental retardation. Also included is development of the hardware and software required to support Chec-Rite. Chec-Rite will be designed to take advantage of existing display, printing, and microprocessor technology. As a result, cost will be minimized to make the product more affordable. The value of the Chec-Rite system will be inversely proportional to the end cost of the device to the user population. Testing of Chec-Rite will be continued in Phase II to determine the optimal design that provides a system that can be easily mastered by the target population.

## DISCUSSION

Chec-Rite will enhance the ability of individuals with mental retardation to master one of the most critical skills necessary for independent living, i.e. effective management of personal checking accounts. The system will automate many of the more mechanical tasks associated with financial management to allow skill training to focus on important money concepts, e.g. is the product worth the asking price. Application of innovative technology can help individuals with mental retardation develop the adaptive skills they may never have achieved otherwise due to cognitive limitations and insufficient training. Chec-Rite will simplify the complicated task of checkbook balancing and check writing and thus enhance the possibility of increased independence for individuals with mental retardation.

## ACKNOWLEDGMENTS

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Daniel K. Davies
Meeting the Challenge, Inc.
3630 Sinton Road , Suite 103
Colorado Springs, CO 80907

10.8

# Responsive Environment Project - Transparent Navigation Assistant

David L. Jaffe, Eric E. Sabelman, Gayle E. Curtis
Palo Alto VA Medical Center


## Abstract

The goal of the Responsive Environment (RE) project is to increase the independence of visually impaired, blind, and cognitively disabled individuals who are navigating through unfamiliar surroundings.

The system will enhance their mobility and orientation by using a flexible arrangement of communication aids. It will unobstrusively guide and inform them with a series of audible prompts (sounds, tones, or digitized voice), tactile maps, or large print displays. These modalities will operate transparently to direct travelers to their destination, taking into account their abilities.

Two scenarios of system activation will be evaluated in this project. One method utilizes transponders (credit-card sized devices which are detected as the user walks by an electronic interrogator) that identify the individual's abilities and destination. Annunciator devices in the environment would then be activated automatically to direct the traveler. In the second arrangement, the user triggers a remote control device when assistance or detailed information is desired.


## Background

Past efforts to give unobtrusive guidance to blind individuals include "talking signs," developed at the Smith-Kettlewell Eye Research Institute [1]. These devices are typically placed above doorways and continuously emit infrared transmissions which are converted into spoken location information when the user aims a hand-held receiver at the door. The Royal National Institute for the Blind proposed an interface concept similar to the RE, but was limited by the available remote identification technology to an "on/off" recognition signal [2]. Navigational aids for the blind include a Japanese system for outdoor guidance using a robot "dog" which signals when the user is on the correct route [3]. Voice Label [4] is a commercially-available wall-mounted recorder/player actuated remotely by individuals who are blind or severely visually impaired.

Wearable memory aids with visual and speech outputs for persons with cognitive disabilities are currently under investigation [5]. Other relevant technology includes environmental control systems that utilize household power distribution wiring to reduce installation costs [6]. These products could be integrated into a RE to provide computer control of electrical devices.

## Research Plan

The goals of the present pilot project are the planning, implementation, and small-scale demonstration of possible configurations for the RE. Promising designs will then be tested within the Medical Center, and later installed in other public sites such as airports, schools, and shopping centers.

## Methods

The initial prototype of the RE is intended for visually-impaired and brain-injured users. Although both groups would benefit from the presentation of navigational information, the differing formats and repetition rates will provide a good test of the RE's adaptability.

The basic scenario for interacting with the RE can best be explained by describing the system's elements.

*Intersection Sensors* - These are radio frequency electronic transponders made by Telsor [7]. A non-powered credit-card sized unit is carried by the traveler. The card's 16 character code defines the user's destination, as well as sensory and cognitive capabilities. When a card passes within range of a fixed intersection sensor, the code is read in a non-contact fashion, providing the system with information about when a particular location is passed by a particular user. (Figure 1 shows these devices.) The RE then activates displays appropriate to the user's capabilities (audio, large print, or tactile). The degree of detail delivered would depend on the user's needs and desires. For example, the amount of information could be programmed to decrease with familiarity. Or, a "discovery mode" could be implemented to give the traveler additional information about the surroundings; for example, what departments and offices are in the vicinity.

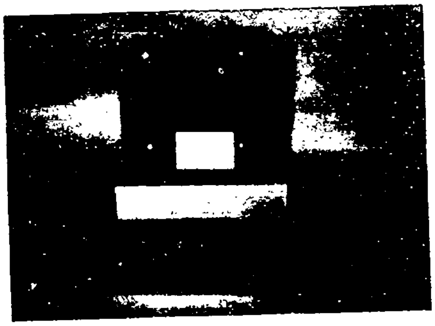

Figure 1 - Telsor card, transponder, and computer interface

*Displays* - At each instrumented intersection, guidance information will be provided to the traveler. Audible options include voice announcements, musical tones, or amplified environmental cues. The information can also be transmitted to a hand-held receiver via an infrared link. Appropriate large print electronic signs will serve sighted travelers. Tactile maps could also be provided, although there is currently no standard format or location for them. The system would have to accommodate the varied reading skills of visually impaired and blind people.

*Node Computers* - These are specialized microcontrollers connected the intersection sensors and displays. They pass the user's location to the Supervisory Computer and return navigation information to the traveler. These computers can also actuate physical assistive devices such as elevators, stair lifts, etc. depending on the user's needs. Under the basic navigation scenario, the system detects the user's presence at a particular node and guides him/her to the next node, where the recognition and direction steps are repeated. Optionally, the node computers can direct the user to a staff person for assistance.

*Supervisory Computer* - This is the intelligent heart of the system. It will control the exchange of commands and data among the node computers. It will have knowledge of the environment including location, type, and current status of intersections sensors, destinations, and "resources". Resources include not only disability-specific aids such as ramps, voice-output elevators, and the like, but also primary and alternate routes to common destinations: locations of optional destinations such as restrooms, snack bars, public telephones, and waiting rooms, and the names and titles of people who staff the facility. Access to these resources will be accomplished in the "User-initiated" and "Rich Info" modes described below.

System elements will be configured, modified, and updated through the Supervisory Computer's keyboard and display. In addition, a Phone Interface will provide verbal destination information to off-site callers. Finally, this system will be used to program the Telsor cards.

*Front Door Kiosk* - This will be a station located at the main building entrance whose purpose is to give the traveler on-the-spot information to reach his/her destination. For sighted users, map information will be displayed on a computer CRT in response to touch-screen destination choices. For blind or vision-impaired travelers, an audio and/or tactile scheme will be implemented. In the former case, the system would issue spoken prompts and the user's choices would be entered with raised buttons on a TouchTone style keypad. The Front Door Kiosk informs the Supervisory Computer of the traveler's needs.

*Network* - This is the hardware which connects the Supervisory Computer to the Front Door Kiosk and the Node Computers located throughout the test site (typically at corridor intersections). Connections between the Node Computers can be implemented in one or more of the following ways: twisted-pair wire, line carrier current (through the AC wiring), radio frequency, infrared, or fiberoptic.

*User wearable elements* - The wearable element of the Intersection Sensors has already been described above. Some users may want to carry a remote control transmitter. Its activation would send an infrared information request to the Supervisory Computer through a local node computer. A handheld audio or visual display would enhance the user's privacy and substitute for the broadcasted modes of information dissemination.

*Software* - Portions of the controlling software will be written in ToolBook [8], an object-oriented HyperCard-type language for PCs. This software will run the Front Door Kiosk and the Phone Interface as well as control the network's node computers with their sensors and displays.

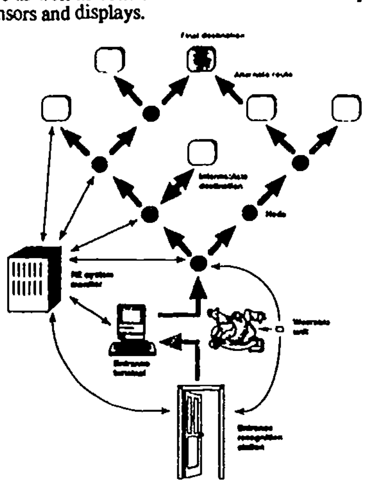

Figure 2 - RE system schematic configuration

The RE will be configured in a flexible manner, permitting operation in many modes and with many strategies for communicating environmental information. Among them are:

1) *Destination-only* - In this mode, a Telsor card will be programmed with the traveler's destination and capabilities. As he/she walks, information will be received in a manner appropriate with his/her capabilities. This information is disseminated transparently, without initiation by the user. Only information which leads to the destination would be communicated.

2) *User-initiated* - In this mode, the user carries a control device. He/she receives information only when the button on the device is pressed. Thus, the user determines when information is required.

3) *Rich info mode* - This mode adds additional capability to the User-initiated mode. When the control device is activated, the user can receive descriptive information about the immediate surroundings as well as destination information.

4) *Non-arrival* - The system will be able to detect the absence of a traveler at a particular node after a programmed time. The system will attempt to communicate with a lost user and send updated destination instructions.

5) *Personal sound* - This traveling methodology uses distinctive sounds to assist a blind or visually impaired user to a destination. At the Front Door Kiosk, the user is assigned a sound (musical notes or animal sound) and instructed to "follow that sound".

6) *Enhanced environmental sounds* - This scenario involves providing sounds normally associated with destinations: flushing (toilet), typewriter (office), pots and pans (cafeteria), drilling (dentist office), ruffling bills (payroll), etc.

Status (Work Accomplished)

*Advisory groups* - The project staff have organized two focus group meetings and have met with six potential users and clinicians to obtain their views and expertise about the functions to be incorporated in a RE, concentrating on blind, visually impaired, and brain-injured users.

*Telsor cards* - A set of four cards and one transponder have been purchased, tested, and interfaced to a PC and a Macintosh. Programs have been written to identify individual cards.

*Simulation software* - To explore the elements of the RE, a visual simulation of the system has been written in an object-oriented graphic environment on a Compaq Deskpro 386. It currently includes a map of the Medical Center grounds, a query screen for picking a destination within the facility, and a navigation and orientation screen which depicts corridor pathways within a simulated building. [Figure 3] In operation, the computer user/traveler picks one of eight locations and is guided by text prompts toward the destination. The user selects the direction of travel and the virtual traveler moves through the corridors. Simulated sensor readings and system responses are displayed in text boxes. As work on this project continues, actual sensors and communication elements will be substituted for the simulated ones.

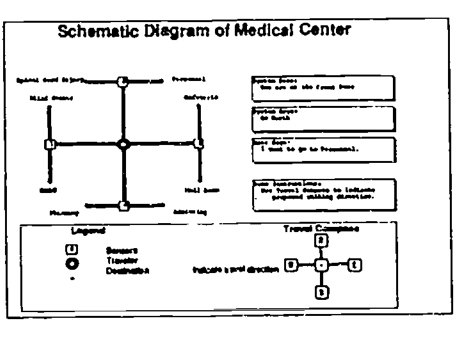


Figure 3 - Screen from ToolBook simulation program

### Future Work

The plan for implementation of the RE consists of the following:

1) A survey of potential test sites selected from: airport, large business, shopping center, university or hospital.

2) Installation of card detectors and information-transfer devices at locations selected from: intersections, elevators, ramps, powered doors, restrooms, information retrieval devices (library catalog, telephone or data terminal) at one site.

3) One-month test with 10 blind and 10 brain-injured users.

4) Evaluation of initial test followed by possible revision of equipment and software.

5) Selection of two sites for upgrade of resources and expanded testing.

6) Enrollment of 100 subjects (half for control group without "smart" identification cards).

7) Installation of 20-30 detector/information transfer nodes at each site.

8) Six-month test of both spontaneous use by subject pool and investigator-monitored trials.

9) Evaluation of 6-month tests; deliverables consist of plans for implementing REs.

### Significance

It is estimated that over 7.5 million non-institutionalized Americans are limited in their self-care activities and occupations by disability or chronic illness [9]. The RE will accelerate the integration of many of these individuals into the mainstream of society by increasing their ability to find their way independently. The RE would relieve therapists and trainers of some of the burden of orienting disabled individuals within their physical surroundings. Under some circumstances, the RE could substitute for a human escort. The proposed RE would reduce the cost of accessibility to the disabled user, who must otherwise invest time and attention beyond that required of the able-bodied, and to the service-provider, who must employ staff and build facilities specifically for informing and directing the disabled. In addition to the public facilities discussed herein, it is anticipated that the RE concept will also be applicable to the home and workplace and for able-bodied people in unfamiliar surroundings. Expansion to other types of disabilities could enhance the independence of elderly, hearing- or mobility-impaired individuals.

### Discussion

Implicit in the study of the RE is estimation of the cost of their full-scale implementation. Obviously, a facility equipped with a RE will contain recognition and communication devices and their interconnecting circuitry that will impose added capital and maintenance costs. However, the RE will incorporate or supplant some equipment ordinarily included in a public facility, such as annunciators, directories, and signs. The RE could also be expected to reduce the labor costs associated with operating an accessible facility, by replacing some human information and escort personnel. Recently passed legislation, such as the Americans with Disabilities Act, will create additional opportunities for disabled people to make use of public facilities. The Responsive Environment concept promises to be a cost-effective approach that does not unduly burden either the disabled user or the operator of the facility.

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### Author's Address

VA Medical Center
3801 Miranda Ave., Mail Stop 153
Palo Alto, CA 94304
415/493-5000 ext 4480

# Awareness and Information Needs about Assistive Devices in Maryland

Dana B. Peterson & Charles A. MacArthur
University of Maryland, College Park, MD
Mary Brady
Governor's Office for Handicapped Individuals, Baltimore, MD

## INTRODUCTION

This presentation summarizes the purposes, methods, and key findings of a survey on awareness and information needs related to assistive technology in Maryland (Malouf, Peterson, Pilato, & Owings, 1991). The survey was conducted as part of the statewide Maryland Technology Assistance Program (TAP). The overall goal of the Maryland TAP is to increase knowledge of and access to assistive technology by individuals with disabilities. The survey had three purposes: (a) to provide data on the use of assistive technology; (b) to provide data on awareness, information needs, and current sources of information about assistive technology; and (c) to provide a baseline for measuring changes in awareness in subsequent years.

## METHOD

Since the Maryland TAP is intended to benefit a statewide population of individuals with disabilities at all ages, the survey sought to represent this diverse population to the greatest extent possible. The survey sample was selected from populations receiving services from special education, vocational rehabilitation, and senior services in six counties in Maryland. The six counties were selected to represent urban, suburban, and rural areas. The sample was stratified by disability category and age for special education and vocational rehabilitation and by age for senior services, and was drawn randomly from the client bases of these three agencies.

Participants were given the option of telephone or mail forms of the survey. Alternate forms were also developed for child and adult samples; seniors and vocational rehabilitation clients were surveyed directly, and parents completed the survey for children in the special education population. Respondents were paid for completing the survey.

## RESULTS

A total of 415 responses were received for a response rate of 22%. The respondents were divided fairly equally across the three agency types and the disability categories. The number of responses was sufficient to support analyses by service agency and disability. However, it should be recognized that the responses may not be fully representative of the total population. Factors such as use of or interest in assistive devices, socioeconomic status, communication difficulties, and other factors may have influenced which individuals responded. Since different agency types, disability groups, and age ranges were approximately equally represented in the samples but not in the populations from which they were drawn, a weighting procedure was used to more accurately reflect their prevalences in the population.

### *Use of Assistive Devices*

The highest percentages of use of assistive devices were found for the vocational rehabilitation population. Ten to 12% of the vocational rehabilitation population used vision aids (other than eyeglasses, which were used by 58%); about 20% used aids to compensate for hearing impairments; about 20% used mobility aids such as wheelchairs or walkers; about 12% used devices for computer access, environmental control, or self-care; and 4% used speech or communication devices such as a communication board or speech synthesizer. Among the special education population, 7% reported using speech or communication devices, 7% reported using mobility devices, 2% used devices for hearing, and 1% used devices for vision (other than eyeglasses, which were used by 38%). The majority of special education students had mild to moderate cognitive/learning or speech/language problems that did not require assistive devices. Among seniors, 21% used mobility aids, 6% used devices for hearing better, and 91% used eyeglasses or magnifying devices.

### *Sources of Information about Assistive Devices*

The respondents were asked about the sources of information they had used in the previous year to find out about assistive devices. "Doctors or other medical people" were identified as the primary source of information about assistive devices by all three groups (with a tie occurring in the special education population). The populations appeared to differ in the other information sources used. For special education, "a place where you get services" was one of the two most commonly used sources, while other sources were used by 10% or less of the population. Vocational rehabilitation respondents indicated use of a greater variety of information sources. "A place where you get services," "pamphlets, books or catalogs," "friends or relatives," "articles in newspapers or magazines," and "television or radio" (in descending order of percentage) were all used by more than 10% of the vocational rehabilitation population. Seniors also reported reliance on multiple sources for information about assistive devices. "Articles in newspapers or magazines," "friends or relatives," "television or radio," and "a place where you get services" (in descending order of percentage) were all used by more than 10% of the senior population.

Respondents were also asked to identify those sources of information that they considered "very helpful." To a large extent these findings reflect those reported above. For the overall population, it appears that the most commonly used sources of information also tended to be "very helpful," with "doctors or other medical people" ranking highest for the overall population and for each agency type.

*Need for Additional Devices*

The TAP survey asked respondents if they needed additional assistive devices that they did not currently have. Among the vocational rehabilitation population, 31% indicated a need for additional devices, with substantially higher percentages for the visual (49%), hearing (38%), and physical/speech (38%) categories than for the cognitive/learning (16%) category. Only 15% of the parents of special education students indicated a need for additional devices. However, 61% of parents of multiply-handicapped students believed their children needed other devices, and higher percentages were also found for parents of children in the visual (38%), physical/health (30%), and hearing (24%) categories. Only 10% of seniors thought they needed additional devices. Furthermore, a considerable percentage of special education, vocational rehabilitation, and senior respondents (23%, 24%, and 19%, respectively) reported that they did not know whether they needed additional devices or not, indicating a lack of information about what assistive technology might benefit them or their children.

*Information Needs*

A major goal of the Maryland TAP is to discover and meet people's needs for information about assistive technology. Respondents were asked to rate the importance of learning more about several topics of assistive technology, including general information about assistive devices; a basic introduction to assistive devices; information about how to get, how to use, how to maintain and repair, and how to pay for assistive devices; and information about what specific devices they or their children needed.

Five of the seven topics were rated "very important" or "essential" by over 40% of the vocational rehabilitation population. The vocational rehabilitation population gave the highest percentage to "how to get assistive devices," followed by "how to pay for assistive devices" and "what specific devices you need." As with earlier questions, higher percentages were found for groups with specific sensory or physical disabilities. For example, over 80% of respondents with visual impairments desired more information about specific devices and how to get and pay for them.

For the overall special education population, the percentages tended to be somewhat lower than for vocational rehabilitation. However, parents of students with sensory, physical, or multiple disabilities rated their information needs much higher. For example, learning about specific devices for their children was rated very important or essential by 81%, 77%, 66%, and 62% of parents of children with multiple, physical, visual, and hearing disabilities, respectively. In contrast, the senior population expressed relatively low needs for learning more about any of the topics listed, with all except "how to pay for assistive devices" rated as "very important" or "essential" by less than 25% of the population.

Conclusions

The findings of the Maryland TAP survey indicate that there is a great need for more information about assistive technology, especially among special education students and vocational rehabilitation clients with sensory, physical, and multiple handicaps. These populations in particular expressed a strong desire for more information about what assistive devices they or their children need and how to obtain and pay for these devices. The results support the need for an organized effort to provide information about assistive technology to individuals with disabilities.

The results of the TAP survey also provide direction on how best to structure an information campaign. All three groups included in this study relied heavily on doctors and other medical professionals for information about assistive technology. Vocational rehabilitation clients and special education students also reported agency service providers as important sources of information. In addition, vocational rehabilitation and senior populations indicated moderate use of printed materials, radio, and television for information about devices. Thus, a successful information campaign will target medical and other service providers, and may supplement these sources with media efforts.

Programs for public awareness and information often rely on information products such as pamphlets, newsletters, media announcements, and public displays. The findings of the TAP survey suggest that such information products may be useful and necessary, but that a more pressing need is for the provision of information services. Existing service providers in such fields as education, rehabilitation, senior services, and medicine may offer the most effective and appropriate means for providing information services. These services should supply individuals with information about what assistive devices they need and how best to obtain them.

The needs expressed by respondents have implications for what specific information services are necessary. The survey found strong needs for information about how to get and how to pay for assistive devices. The Maryland TAP can address these needs by providing consultation on existing devices and the means available for obtaining them. These services should help individuals navigate through the often confusing process of finding and financing assistive technology.

The TAP survey included only individuals within Maryland. However, great care was taken in the sampling process, with the resulting sample fairly equally distributed across three separate service agencies. Because of the study's careful sampling plan and its use of three large client bases, the sample may also be representative of disabled individuals outside Maryland. The results of the Maryland TAP survey may be useful to other states in determining their residents' needs for information about assistive technology.

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Dana Peterson
University of Maryland
1220 Benjamin Building
College Park, MD 20742

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11.2

# TECHNOLOGY COMPETENCIES AND TRAINING GUIDELINES FOR OCCUPATIONAL THERAPISTS

American Occupational Therapy Association Technology Special Interest Section
Joy M. Hammel, MEd, OTR, Palo Alto VAMC RR&D Center; Roger O. Smith, MO, OTR, Trace R&D Center
Judy Rein, MS, OTR; Kennedy-Kreeger Institute; Denis Anson, MS, OTR; Univ. of Washington, Seattle

## ABSTRACT

A set of technology core competencies and training guidelines for occupational therapists (OTs) has been drafted by the Technology Special Interest Section (TSIS) of the American Occupational Therapy Association (AOTA). Competencies are delineated into three levels: knowledge, general technologist, and specialized technologist. This set is intended to serve as a basis for providing technology training to OTs at the pre- and post-professional levels, as well as to serve as a training model for other rehabilitation technology professions, such as rehabilitation engineering, and physical and speech therapy..

## BACKGROUND

Technology has served as one of the primary tools of occupational therapists since the profession started in the early 1900's. Light and high technologies have been used to improve the functional performance of individuals with disabilities within the community, work, play and school settings. Many recent trends in our society have increased the use and proliferation of commerical and assistive technologies. Due to the changing nature of our society imposed by the Information Age, individuals are now required to access and use many technologies, such as computers, networks and faxes, on a daily basis.

Assistive technologies, such as wheelchairs and adapted computer access devices, are becoming increasingly available and sophisticated. Five years ago, access to adaptive technologies, particularly high technologies such as computer access devices, was extremely limited. Individuals with disabilities were forced to adapt themselves to fit the limited capabilities of the technologies. Today, there is an increasing range and sophistication level of technologies, from low to high tech, from which to choose, giving consumers the opportunity to customize and integrate many technologies to fit their specific needs and life goals.

Recently, our society has seen a grass roots movement among individuals with disabilities which has resulted in several key pieces of legislation. Key legislation, such as the Americans with Disabilities Act (PL 101-336), the Technology Related Assistance for Individuals with Disabilities Act (PL 100-407), the Rehabilitation Act (PL 99-506) and Amendments of 1986, and Education for All Handicapped Children Act (PL 94-142), mandate that children and adults with disabilities be given equal access to technologies which enable them to function in the community, school, and workplace, and that monies and services be appropriated to train professionals in the application of these technologies.

Access to technology has become as critical a need for individuals with disabilities as is access to the physical environment. Therapists must be aware of and competent in the evaluation, prescription, operation, and adaptation of technologies if they are to meet the changing needs of individuals with disabilities.

The increased use of technology has also introduced many emerging areas of service delivery in which rehabilitation professionals, including occupational therapists and rehabilitation engineers, can become involved in, such as adaptive computer access assessment, ergonomic analysis, and worksite accommodation. Therapists must extend service delivery outside of the traditional clinic setting to the schools and worksites. They must be competent in working within a multidisciplinary service delivery team which may include physical and speech therapists, medical professionals, engineers, teachers, rehabilitation counselors, employers and vendors, as well as a variety of internal and third-party reimbursement sources. Therapists must also function in the role of consumer advocate, working with consumers to ensure access to and funding for enabling technologies.

All of these trends demonstrate the importance of technology in our society and the need for therapists and all rehabilitation professionals to be knowledgeable in the application of these technologies. However, surveys of occupational therapists and therapy programs have found this need has been relatively unmet and have demonstrated the critical need for ongoing technology training on both the pre- and post-service levels [1,2].

## OBJECTIVE

In response to the need for technology training, the American Occupational Therapy Association (AOTA) has developed a new Technology Special Interest Section (TSIS). The goal of the TSIS is to serve as a central clearinghouse and networking base of technology-related information and expertise. One of the primary projects of the TSIS is to develop and evaluate a set of technology-related competencies and training guidelines for occupational therapists.

## APPROACH

Before drafting the competencies, an extensive list of content to be taught was identified by the TSIS members, expert clinicians, educators, and searches of the RESNA and AbleData databases (see Table 1). In addition to the traditional content categories of control, communication, and mobility, the list was extended to include funding/reimbursement, service delivery, information dissemination, and technology transfer. A set of core competencies was drafted from this list. Competencies were split into three levels: knowledge, general technologist, and specialized technologist.

### *Knowledge*

The knowledge level applies to minimum competencies all therapists should possess upon completion of pre-professional training. Therapists at this level will provide technology-related treatments with supervision and triage and referral services to clinicians at the general and specialized levels. It is critical that therapists at this level be competent in the identification and use of technology resource networks and databases to refer clients to the appropriate technology evaluation and prescription services.

### *General Technologist*

Therapists at the general technologist level have completed additional technology training through a specialized program, such as the University of Wisconsin-Madison's OT TechSpec program [3], and an additional 50-60 hour clerkship with a general or specialized OT technologist. General technologists may serve as Technology Team Coordinators and provide unsupervised technology-related treatments; however, they are not qualified to provide specialized technology evaluations.

### *Specialized Technologist*

The specialized technologist has developed an expertise in a specific application of technology, such as seating and positioning or worksite accommodation. Therapists at this level are qualified to develop and conduct technology assessments and provide specific troubleshooting.

Therapists at the general and specialized levels are encouraged to participate in the development and evaluation of new technologies and design and implementation of technology-related research projects.

| Technology Training Content |
|---|
| Accessible Architectural Design |
| Administration & Management |
| Augmentative & Alternate Communication (spoken & written) |
| Biofeedback |
| Computer Applications (hardware & software) |
| Education |
| Environmental Control |
| Funding |
| Information Networking |
| Interface Design |
| Job Accommodation |
| Legislation |
| Light/Daily Living Technologies |
| Neuromuscular Electrical Stimulation |
| Orthotics & Prosthetics |
| Personal Care Aids |
| Personal Transportation |
| Quantitative Functional Assessment |
| Recreation |
| Research & Development (Technology transfer) |
| Robotics |
| Seating & Positioning |
| Sensory Aids |
| Service Delivery |
| Wheeled Mobility |

Table 1. Areas of technology content on which competencies and training guidelines are based.

## RESULTS

To date, the first set of core competencies for knowledge-level therapists completing pre-professional training has been developed. Each competency is accompanied by training guidelines and suggested methodologies and existing resources which can be used within OT curricula. This detailed set is available through the TSIS. A set of similar competencies which emphasizes innovative methods of providing continuing education is being drafted for therapists who have been practicing for many years, but need additional training to learn about new technologies and to remain current on the latest advancements, legislation, and emerging areas of service delivery.

Upon revision of this set, the competencies will be reviewed by AOTA and be distributed to OT training programs for implementation and evaluation.

## DISCUSSION

The core technology competencies developed by the TSIS emphasize the role of the occupational therapist within a multidisciplinary service delivery team. Competencies specifically tap into the existing knowledge base of occupational therapists; that is, the expertise of the therapist in identifying the needs of individuals with disabilities and in integrating various technologies (light, high, assistive, rehabilitative) which will optimize functional performance within the home, work, school and play environments.

At the knowledge level, therapists are not required to possess the same knowledge of technology as that of other rehabilitation professionals, such as engineers; but rather, to have an overall understanding of the specific roles of each team member in the service delivery of technology and the ability to locate and tap into the services of these professionals to assist in the evaluation, prescription, and technology transfer process. For example, a knowledge-level OT is not required to be able to fabricate a switch from scratch or to program a HyperCard stack to run an environmental control unit. Instead, therapists must be able to identify information resources and databases which will help them locate commercial devices, identify local consumers already using these products, contact general or specialized OT technologists who can perform further evaluation and prescription services, and identify other rehabilitation professionals (engineers, technicians, therapists, consumers, vendors) who can help to fabricate or adapt these technologies and train the knowledge-level therapists how to use and incorporate them in their practices.

Although the competencies were specifically designed for OTs, they are relevant to and can be adapted for other rehabilitation professions including physical and speech therapy, engineering, special and regular education, and rehabilitation counseling.

The drafting of this set of competencies is the first step in providing comprehensive, quality technology training to occupational therapists. This list focuses primarily on training within pre-professional university-based OT programs. There is still a large number of occupational therapists who have been practicing for many years who need technology training on introductory and advanced bases. In the future, the TSIS plans to develop a similar set of competencies and continuing education training guidelines for this group of practicing therapists, and for therapists who aspire to become general and specialized technologists. Compentencies for general and specialized technologists will be developed in conjunction with other professional groups drafting similar guidelines including RESNA, ASHA, and the Council for Exceptional Children.

## ACKNOWLEDGEMENTS

The authors would like to thank the American Occupational Therapy Association, especially Carol Gwin, for their support and assistance in developing the TSIS and these guidelines.

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## AUTHOR'S ADDRESS

Joy Hammel, MEd, OTR
Palo Alto Veterans Affairs Medical Center
Rehabilitation Research and Development Center-MS 153
3801 Miranda Avenue
Palo Alto, CA 94304

*OR*

AOTA Technology Special Interest Section
American Occupational Therapy Association
% Carol Gwin, OTR
Practice Division
1383 Piccard Drive, PO Box 1725
Rockville, MD 20849-1725

# THE COST EFFECTIVENESS OF OUTREACH

Robert Michael Jones, Benjamin E. Brown, Kathleen A. Kolar
Department of Rehabilitation Engineering
University of Wisconsin Hospital and Clinics
Madison, Wisconsin

## INTRODUCTION

In recent years, several Rehabilitation Technology programs have reported on their experiences traveling to clients rather than having clients travel to the Rehab. Technology Center.[1,2,3] The reports have concentrated on the means of service delivery, usually specially equipped vans to provide on site fabrication services.

The Department of Rehabilitation Engineering of University of Wisconsin Hospital and Clinics designs and fabricates custom seated positioning systems. The Department established an Outreach Program in 1981. For the first two years, department staff traveled from Madison, to see clients located throughout much of the state of Wisconsin. Trips were to schools, nursing homes or community agencies where several clients could be seen in one day. The trips were on a regular schedule. Staff members traveled once or twice each week. An individual client could rely on being seen every 5th week. The length of the trips varied from approximately 100 to 300 miles round trip.

In 1983, the Department hired staff members who lived in the more distant Outreach areas served. We felt having staff members located in the geographical areas served would provide better service because they would be available between Outreach visits and they would facilitate coordinating appointments and outreach visits. Madison-based staff members continued to travel to these Outreach areas. Clients were seen by a team consisting of a Madison-based staff member and the new "local" staff member.

A management accounting system was developed to monitor the financial performance of each Outreach Area and to provide feedback to all staff members on financial activities. In this accounting system, revenue is obtained from charge documents filled out whenever patients are seen. Expenses are divided into three broad categories: 1. Materials, which includes the seating systems fabricated for the Department by an outside vendor, metal brackets, shop supplies and shop personnel. 2. Professional staff, which includes both the "local" and Madison-based staff. Charges for the Madison-based staff include travel time and vehicle charges. 3. Department overhead which includes secretarial staff, management and other general expenses.

The accounting system includes separate "areas" for clients seen at University Hospital in Madison, for those Outreach clients seen only by Madison-based staff and for clients seen for "special projects".

## METHODS

The management accounting system was used as a data base to examine the question of cost effectiveness of alternative service delivery models. The geographical areas in the accounting system can be grouped into one of three service delivery models:

1. Center Based, No Outreach
2. Local Outreach
3. Outreach With Local Staff

The Center Based area with No Outreach is for clients seen at University Hospital in Madison. This would correspond to the traditional model of a Rehabilitation Engineering Center. Clients travel to a central facility which has a large staff and extensive equipment.

The Local Outreach area is for clients who live close to University Hospital and are served by Madison-based staff members who travel to the client. This type of service delivery corresponds to the traditional wheelchair vendor. Travel is to local facilities such as schools, nursing homes and community agencies. The length of the trips seldom exceeds 100 miles round trip.

Outreach With Local Staff are "areas" with staff members who live outside Madison and have regularly scheduled trips by Madison-based staff members. Most clients are seen at centralized locations within the area by both the Madison-based and local staff members. The local staff member travels to see other clients. Trips by the Madison-based staff members are 200-300 miles round trip. Trips by the local staff are less than 75 miles round trip.

## RESULTS

Data was taken from the managerial accounting system for four consecutive years (fiscal years 86/87-89/90). During this period, the Department averaged approximately 1,700 client visits and 300 new seated positioning systems per year. The seating systems were constructed of plywood and foam and manufactured by local vendors to specifications provided by the Department of Rehabilitation Engineering.

The ratio of revenue divided by expense (expressed as a percentage) is used as a measure of financial efficiency for each type of service delivery. A ratio of 100% would be considered breakeven.

The results for the four types of service delivery are shown in Table 1. An analysis of variance revealed that differences between years or types of service delivery are not statistically significant.

TABLE 1. COST EFFECTIVENESS OF ALTERNATIVE SERVICE DELIVERY MODELS

| SERVICE DELIVERY MODEL | REVENUE/EXPENSE RATIO |
|---|---|
| Center Based, No Outreach | 129% |
| Local Outreach | 126% |
| Outreach With Local Staff | 119% |

DISCUSSION

It seems intuitive that traveling to see clients should be more expensive than having clients travel to your center. This is not supported by our results and by anecdotal results from other centers. In our experience, seeing patients on Outreach trips is more efficient because staff waiting time is reduced or eliminated. When clients travel to see us, they often arrive late or cancel their appointments with little advance notice. When we travel to see clients, there is no lost waiting time. At facilities where we see several clients, such as nursing homes or schools, clients are available as soon as we are free to see them.

There are other service delivery programs that travel to remote centers, but having a local area coordinator is uncommon. Having both centralized and "local" staff members is a feature of programs in Montana[4] and South Carolina[5]. This type of program might be described as a "distributed".

Traveling to see patients has an additional benefit. INPUT!! When clients travel to University Hospital to see us, they are rarely accompanied by more than one person who works/lives with them. When we travel out to see clients, usually parents/attendants, teachers and therapists are present. Having the additional people present, allows a much more complete explanation of what needs the equipment should address. The needs may be contradictory, but Rehab. Engineering staff can point out the contradictions and present alternatives. The final decision, made by everyone present, insures a good match between equipment and client needs.

We have found Outreach a means of providing quality equipment in a cost effective manner.

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# A Computer-Based Information Management System for a Rehabilitation Engineering Service Delivery Program

Gerald Weisman and James P. Tranowski
Rehabilitation Technology Services
Vermont Rehabilitation Engineering Center
Burlington, Vermont

*Abstract*

It is becoming increasing important to assure the quality of rehabilitation engineering and assistive technology services. An important part of any quality assurance program is the data management system. Any data system must be able to provide critical information about people served, services provided and other activities of the program. Rehabilitation Technology Services, an affiliate of the Vermont Rehab Engineering Center has developed a comprehensive Dbase III+/Clipper information system that is easy to use and is capable of tracking clients, services and other necessary information.

*Introduction*

The provision of assistive technology and rehabilitation engineering services has grown significantly during the last few years. With legislation such as the "Tech Act," Americans with Disabilities Act, changes in education laws and proposed changes in the Rehab Act, it is anticipated that these services will continue to grow.

As more service programs are established it becomes increasingly important to assure the quality of services. An important part of any quality assurance program is the collection of appropriate data. This information is vital in evaluating a program's performance, such as types of clients served, actual client flow, average income/loss per client, future client flow projections, material/labor costs, quarterly or annual profit/loss statement, etc.[1] This information is important for program planning and accountability.

Rehabilitation Technology Services (RTS) was started in 1983 as a private partnership to provide rehabilitation engineering and assistive technology services to the northern New England area. In 1985 the company was moved to Vermont and became an affiliate of the Vermont Rehabilitation Engineering Center at the University of Vermont. It is still run as a small business as part of the Orthopaedic and Rehab clinical practice group.

RTS provides rehabilitation engineering consultations as well as fabrication services, information and referrals and educational programs and workshops. Almost all areas of assistive technology are covered by RTS services particularly; worksite modifications, educational and classroom accommodations, mobility and seating, communication, computer access, devices for activities of daily living and architectural accessibility. The services of RTS have been expanded greatly during the last due to a contract with the Vermont Assistive Technology Project funded through the "Tech Act." These expanded services include a mobile service delivery program that supports local mobility and seating clinics with engineering consultation and "try-out" equipment and expanded computer and augmentative communication services including a "try-out" center with equipment.

It has always been important to track information about the services we provide. This information has been helpful in identifying good sources of referrals as well as the actual costs incurred in providing the services and the income generated. The need for a comprehensive data collection system was identified early on in the development of the program. This paper describes the computer based data collection system developed specifically for Rehabilitation Technology Services and provides illustrations of how the data is analyzed and presented.

*Evolution of Information System*

The current RTS information system uses a DBase/Clipper tool. The original information system relied on a single DBF file, and used a multi page "Format" Screens to govern entry. We began with a schema wherein all the information to describe any possible activity (as well as the complete client demographic record) are held in a single DBF record. Because only the first occurrence of a client's record carried all the valid personal information. However, if changes were to be made (new telephone number), then the user would have to locate that first record, or the changes would be lost. This structure presented specific problems and inefficiencies in handling the data including:

1. Managing client info -- Hybrid: Paper/Disk. Client ID's are managed by keeping track of each Client's folder.
2. Multiple use of "PgDn" key to find correct form. This requires extra time and effort.

The capacity to produce valuable reports was compromised due to the structure of the information system. There was massive wasteful duplication of fields that were always by default unused and blank. There was a major opportunity for user error that could corrupt the real history that this system was set out to record.

The system was modified using a DBase III+ menu driven system which has ultimately evolved into a system using Clipper V5.01 with Rtlink+.

*Design of Computer Based Info System*

The goals for the system are: a) to have an accurate record of program activities, b) streamline the clerical user's input task, and c) to provide for meaningful online and hard copy reporting functions.

**Needs and Objectives of System**

The specific information needs of the service delivery program were defined and objectives were developed for the computerized information system. These objectives included:

1. Rehab technology practice
   A. Single provider
   B. Growth to second, etc. providers
2. Capture daily activity of provider(s)
3. Ease/power of functional interface for clerical staff
4. Eliminate any/all double entry (re-keying)
5. Accurately and effectively
   A. Record data
   B. Portray historical & financial record (on screen)
   C. Provide for reports

**Structure of Database**

The database is structured around three pivotal or "key" fields which are integral to the conceptual functioning of the RTS Database. These fields are:

1. Client ID number
2. Service/Activity code
3. "Funded?" question

Each unique client record must be assigned a unique (usually an ascending integer) ID number or code. Any/all service and activity records must carry this ID, which forms the basis of a relational lookup.

Each service/activity record must carry a "SVC" code. These are defined on the paperwork filled in by providers; the list of these is subject to periodic additions. The SVC code is indicative of the kind of service that was performed, i.e. information provided, consultations, engineering design, fabrication or training.

Each service/activity record carries a flag indicating as to whether it is "funded" or not. If set to "true", then additional forms may be enabled to the clerical user for entry of this related information.

The system was established as a menu driven system using DBase III+ PRG program files. The original massive-single DBF file was separated into three individual DBF files. Client records (CLIENT.DBF) would be entered only once. The service record (SERVICE.DBF) describes the service provider, the nature of the service, a few related details, and a flag telling whether or not this activity has been funded. The third file is the activity file (ACTION.DBF). This file contains fields for all dates, times, charges, and payments associated with this activity.

There was one weakness with this "Relational" approach, due to the runtime way that DBase III+ works. While these 3 files were logically linked via several key fields, during record selection activities where we used BROWSE FIELDS, the user was always free to alter these fields. Additionally, fields were open to be altered if the user chose to bypass our menu structure, and invoke the DBase III+ EDIT or APPEND command.

The database was further refined by using Clipper V5.01 with Rtlink+ to produce a single "EXE" file which covers all the functions for RTS in a single stand-alone program. The Clipper version of the database system resolves many of the problems faced by using the Dbase III+ menu driven version. The look and feel of the overall package was improved with such features as:

1. Unify into a single consistent set of keystrokes: <Ret>, <Esc>, and a very small number of <Fn> function keys.
2. Quicker response and more direct path to desired functions. Multiple choice form entry's are now served by POPUP pick lists, eliminating entry of INVALID values.
3. Control-fields which are crucial to the relational linking of the 3 separate DBF's are no longer exposed to errant or inadvertent user erasure or destruction. At the same time, the relational links between the 3 files are being emphasized, permitting the user to activate a UNIFIED BROWSE, which automatically effects the ONE-TO-MANY link between CLIENT Records and the SERVICE/ACTIVITY pair.
4. On Line HELP, using a context-keyed DBF/MEMO pair.
5. Better integration w/ MS-DOS (3.30+) Clipper uses its own virtual memory System, freeing us from the 640KByte barrier of MS-DOS

**Reports**

The strength of any information management system is the ability to create useful reports about the activities of the program. We have used our system to create a number of reports describing the nature of services that have been provided, the kinds of clients, the sources of referrals, the nature of the disabilities and functional limitations of the clients served, etc. In conjunction with standard accounting procedures and reporting techniques, our information system has provided valuable data on how and when services are funded.

In order to visualize our data we have created a link with Harvard Graphics to produce graphs. Figure 1 demonstrate the distribution of ages of the clients seen by RTS. Figure 2 illustrates the categorization of services provided by RTS. As can be seen, most services involved "Postural Seating" and "Worksite Modifications." The figures represent the percentage of 350 clients seen over 5 years.

***Conclusion***

A computer based information system has been created to track information about clients, services and funding for a private rehabilitation engineering/assistive technology service delivery program. The system has proven to be effective in tracking and presenting critical information about who is being served and what kinds of services are being provided. The system has contributed to improving the delivery of services and the growth of the program.

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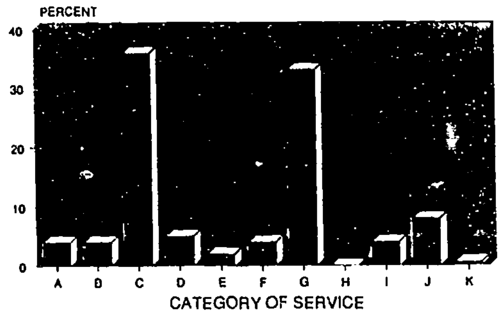
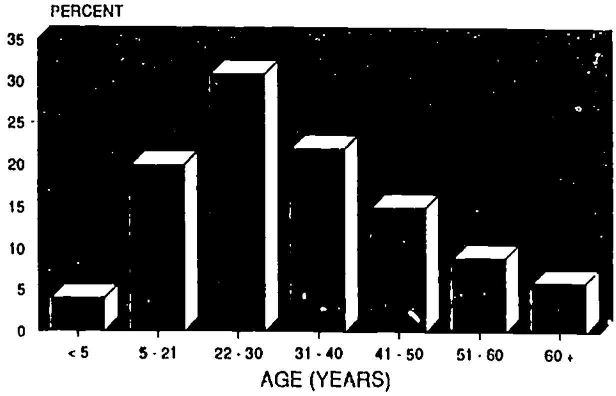
REHABILITATION TECHNOLOGY SERVICES
CLIENT - 5 YEARS




A: Arch Access
B: LBP Seating
C: Post. Seat.
D: Power Mobility
E: Aug Communic
F: Computers
G: Worksite Mods
H: Other Mobility
I: Transport
J: Home Mods
K: Ergonomic Study
L: P & O

REHABILITATION TECHNOLOGY SERVICES
CLIENTS - 5 YEARS



11.5

# How to Teach about Technology: Developing a Syllabus on Assistive Technology for Rehabilitation Educators

John R. Schweitzer, Paul N. Hale, Jr. and Frank D. Puckett
Center for Rehabilitation Science and Biomedical Engineering
Louisiana Tech University
Ruston, Louisiana 71272

## Abstract

National policy in recent years has emphasized technology-related assistance as an integral part of rehabilitation case services. This has created a need for counselors-in-training to receive instruction in the application of assistive and rehabilitative technologies for persons with disabilities. A training program was designed to provide rehabilitation educators with an exposure to rehabilitation technology and provide an instructional syllabus to facilitate teaching about assistive technology within their counselor training curricula.

## Background

Contemporary legislation in the area of assistive technology includes the 1986 Amendments to the Rehabilitation Act mandating greater use of rehabilitation engineering services, the Technology-Related Assistance for Individuals with Disabilities Act of 1988 which establishes statewide systems change in access to assistive technology, and The Americans with Disabilities Act of 1990 which indicates the role for technology in providing "reasonable accommodation" for persons with disabilities. Rehabilitation technology is a relatively new feature in rehabilitation programs and few rehabilitation counselors have received formal training in this area. This has led to some apprehension on the part of rehabilitation staff. Appropriate training can help demystify assistive technology and help rehabilitation staff become more comfortable with this new "tool" for rehabilitation. Perhaps there is no other state agency function that is more important than providing complete on-going training to counselors and supervisors who have responsibility for providing services to their clients in this area (Corthell and Thayer, 1986). Just as accountability and quality assurance are important in traditional rehabilitation practice, there should be a committment to assuring that quality services are provided in assistive technology. Rehabilitation counselors have the ultimate responsibility to see that evaluations for assistive technology are performed by competent staff.

## Objective

The objective of this training program was to provide rehabilitation educators with an overview of rehabilitation technology as well as experience in various assessment laboratories and hands-on experience with assistive devices. The training included the following elements.

- Overview of assistive technology in rehabilitation practice.
- Development of instructional course material.
- Review of a proposed syllabus and support material.

One of the instructional sessions dealt with locating assistive technology resources in one's local area. The goal of this training program was to provide the rehabilitation educator with resources and guidance for teaching a two-hour instructional unit on rehabilitation technology service delivery.

## Methods

Eleven rehabilitation educators were recruited from the south-central area of the United States representing the following ten universities:

- Arkansas Tech University, Russellville, Arkansas
- East Central University, Ada, Oklahoma
- New Mexico State University, Las Cruces, New Mexico
- University of New Mexico, Albuquerque, New Mexico
- Stephen F. Austin University, Nacogdoches, Texas
- University of Texas - Southwestern, Medical Center of Dallas, Dallas, Texas
- University of North Texas, Denton, Texas
- Southern University, Baton Rouge, Louisiana
- Louisiana State University, Allied Medical Center, New Orleans, Louisiana
- Mississippi State University, Starkville, Misssissippi

The training approach for the rehabilitation educators was guided by directing the instructional content towards the following questions:

1. What is happening in rehabilitation technology; what is the current state-of-the-art in this field?
2. How do rehabilitation professionals locate and use local resources to obtain assistive technology services?

Each faculty member from the represented universities received an instructional manual which included the following components:

- An outline of instructional modules on four areas of assistive technology service delivery - Wheelchairs and seating, Augmentative communication, Independent living devices, and Adaptive driving and personal transportation.

- A prepared narrative of five to six pages, suitable for in-class lecture, which discusses definitions of key terminology, describes examples of assistive devices, and recommends procedures for gathering assessment information to identify an individual's need for assistive devices.

- A list of media resources on each topic to include possible guest lecturers from local hospitals and/or rehabilitation facilities.

- Recommended strategies for evaluating the learning achieved by the students by use of prepared test items.

Multiple-choice test items were developed for each content area. These items were formatted to ask for recognition of correct definitions, recall of technical and clinical terms and fill-in-the-blank "stems." No empirical validation of the items was anticipated or planned. Each rehabilitation educator was to determine the appropriateness of the test items for his/her particular situation.

In this seminar, a significant amount of time was committed to actual experience with assistive devices in various assessment laboratories.

- A simulated model apartment which displays various adaptive devices for eating, food preparation, dressing, bathing, grooming, and environmental control.

- Seating and positioning laboratory in which staff conduct assessments for manual and powered mobility and corrective postural seating systems.

- Adaptive driving laboratory for the assessment of the physical and cognitive attributes of driving a personal vehicle.

- Laboratory for the assessement and prescription of augmentative communication devices.

- Assistive Devices Information Services (ADIS) laboratory for storage and retrieval of information about rehabilitation technology.

Results

This training program and syllabus attempted to provide rehabilitation educators with the resources and knowledge to meet the needs of their rehabilitation counselor training programs. Unsolicited follow-up from attending educators included comments such as the following: "I regard my participation in the seminar as an excellent investment of my time. The print and audio-visual materials provided for participants will be very useful in the classroom. I have already began to share the material with my colleagues."

A telephone survey was conducted six months following the on-site training. The survey results indicate that 80% of the participants have used the syllabus materials in teaching classes studying rehabilitation service delivery. Of those who have used the material, 88% reported the material to be "very useful." Those who had not used the material planned to teach a section in which they will use the syllabus in the fall semester, 1992.

If this training is carried forward as planned, it is expected that counselors-in-training who receive this instruction will be better able to address the assistive technology need of clients on their caseload upon employment in a rehabilitation setting.

Acknowledgements

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Dr. John R. Schweitzer
Center for Rehabilitation Science and Biomedical Engineering
Louisiana Tech University
Ruston, Louisiana 71272

# Exploring the Role of Consumers as Volunteers in the Delivery of Assistive Technology Services

Anthony J. Langton, Vicky Smith, Thomas Poland and Ronald Parker
Center for Rehabilitation Technology Services
South Carolina Vocational Rehabilitation Department
West Columbia, South Carolina

## ABSTRACT

Many gaps exist in our current service delivery systems. Exploration of innovative methods for delivering assistive technology services raised the possibility of the role volunteers could have in a service delivery system. Consideration of what role individuals with disabilities might perform as "consumer volunteers" started as a result of discussions on the importance of consumer involvement and the "empowerment" movement. Findings indicate that volunteers are being utilized to provide a significant portion of assistive technology services in many programs. Utilizing consumers in volunteer capacities is being done and represents one way to increase meaningful consumer involvement. Although volunteers represent an attractive alternative method of service delivery, there are many considerations which should be investigated when considering any type of volunteer program.

## INTRODUCTION

Many gaps exist in our current service delivery systems. The need for access to information and other assistive technology services continues to grow while the level of available resources remains limited. Programs are increasingly forced to seek delivery models which economize on costs and stretch existing capabilities. Volunteers represent a potential way for assistive technology programs to supplement available staff and fill some of the gaps which exist in most service delivery systems. This approach has particular promise for rural communities and areas where technology resources and services are undeveloped.

## BACKGROUND

Volunteers have long made substantial contributions to the services and effectiveness of diverse organizations. Throughout our history, volunteers have been active in hospitals, schools and in the community. Volunteerism is an essential component in contemporary society and a very necessary part of many social programs. Hospitals in particular have grown to depend on volunteers to offer services and extend that "extra effort" to meet the needs of patients and their families.

Limited resources exist to assist consumers in getting through the service delivery process or to suggest where to go to receive appropriate assistive technology. The idea of people with disabilities serving as volunteers in providing assistive technology services and related services to other people with disabilities is a relatively new concept. A few known programs were mentioned although little documentation on their success and failures exist.

Exploration of innovative methods for delivering assistive technology services raised the possibility of the role volunteers could have in a service delivery system. Volunteers represent a powerful force. Groups such as the Telephone Pioneers of America and Volunteers in Medical Engineering (VME) have established reputations as valuable resources for technology related assistance. Preliminary research, however, suggested that volunteers as a group were an under-utilized resource in the area of assistive technology.

Consideration of what role individuals with disabilities might perform as "consumer volunteers" started as a result of discussions on the importance of consumer involvement and the "empowerment" movement. South Carolina is a state which traditionally has not had significant levels of consumer involvement or self advocacy. Despite this historical trend, a number of individuals with disabilities have expressed strong interest in becoming involved in volunteer capacities.

Questions to be addressed

1. What role do volunteers play in the delivery of assistive technology services ?
2. What type of technology related services do volunteers assist in providing ?
3. Are consumers being used as volunteers in assistive technology service delivery ?
4. What similarities or differences exist in the utilization of consumer volunteers ?

## METHOD

The survey was mailed to 431 programs throughout the United States known to serve individuals with disabilities. Consumer advocacy organizations, National Easter Seal and United Cerebral Palsy Association affiliates, state programs funded under the Technology Related Assistance Act and rehabilitation engineering programs participated in the survey. These programs were randomly selected based on knowledge that they were thought to provide assistive technology and related services. It was not known whether these programs had volunteer service components.

## SURVEY FINDINGS AND ANALYSIS

Of the 481 surveys distributed, a total of 124 programs returned the questionnaire (25%). A breakdown was made by three geographic areas: South Carolina, the Southeast region (RSA Region IV), and The Nation. A comparison was also made of the states which had been awarded Technology Related Assistance Grants in 1989 and 1990. Of the 22 surveys sent, 10 responses were received.

Surprisingly, all 124 programs (100%) indicated that they did utilize volunteers in some aspect of their services. Further analysis showed that 79 programs and agencies (65%) actually used volunteers in technology related services.

Analysis was completed on the types of services provided and what role, if any, volunteers had in these specific services. Figure 1, shows the services provided and the level of volunteer involvement reported.

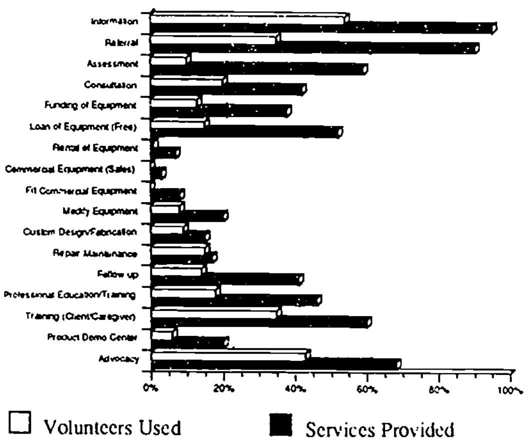


Figure 1. Role of Volunteers in the Delivery of Assistive Technology Services

In reviewing the roles of volunteers, several patterns consistently surfaced. Information, advocacy, referral and training (client/care giver) were services where use of volunteers was consistently highest among all breakdowns. Analysis of the types of volunteers used (Figure 2.) showed Professionals, Any interested person, Consumers and Retired persons as being most utilized.

| | National | Southeast States | Tech Act States | South Carolina |
|---|---|---|---|---|
| | % | % | % | % |
| Consumers | 54 | 43 | 100 | 47 |
| Professionals | 60 | 57 | 100 | 58 |
| Parents | 51 | 40 | 85 | 26 |
| Students (H.S.) | 29 | 37 | 0 | 37 |
| Students (Coll.) | 48 | 47 | 43 | 42 |
| Any Interested Persons | 67 | 73 | 71 | 63 |
| Retired Persons | 61 | 73 | 14 | 79 |
| Other | 10 | 7 | 14 | 5 |

Figure 2. Types of Volunteers Used

Surprisingly, in response to the question," Do you require a particular background or qualifications for volunteers?" Only a small percentage (26 -35%) required specific qualifications. An exception to this was the Tech Act projects where 71% reported specific requirements. These programs were found to also have the highest level of consumer volunteers.

Other responses on "types of volunteers" made reference to Telephone Pioneers, Volunteers in Medical Engineering, Junior League, use of mentally handicapped individuals, military, National Labor Engineers, non-disabled volunteers from social/recreation and court ordered service.

## Consumer Volunteers

Varying levels of use of consumers as volunteers were found. Figure 3. indicates the approximate level of consumer volunteer use in the reporting groups.

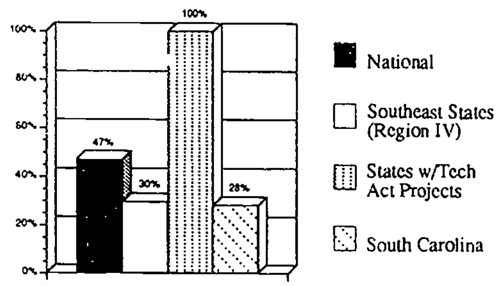


Figure 3. Use of Consumers as Volunteers

The level of consumer volunteer activity in the Southeast appears to be significantly lower than in the National sample. No specific reasons were indicated to explain this variation. Development of consumer volunteer activity in the Southeast may be helpful in increasing the overall level of advocacy and consumer activity.

Comparison of consumer volunteers with the total group of volunteers showed similar levels of utilization (see Figure 4.). As with all volunteers, consumers were primarily used to provide information, advocacy, referral and training (client/care giver).

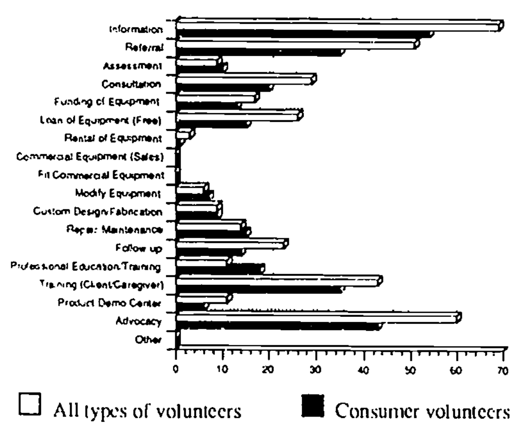


Figure 4. Comparison of Consumer Volunteers with all Types of Volunteers

Use of volunteers in providing services otherwise not available and reducing service delivery cost were consistently ranked as primary benefits. Figure 5. shows reported benefits for all groups.

| | National | Southeast States | Tech Act States | South Carolina |
|---|---|---|---|---|
| | % | % | % | % |
| Provide Services Otherwise Not Available | 64 | 57 | 57 | 68 |
| Reduce Service Delivery Costs | 64 | 67 | 43 | 63 |
| Serve People Otherwise Not Served | 43 | 47 | 57 | 58 |
| Provide More Timely Services | 46 | 47 | 43 | 37 |
| Other | 20 | 23 | 29 | 21 |

**Figure 5.** Primary Benefits of Using Volunteers

## DISCUSSION

Many important issues remain to be resolved. Volunteers are being utilized to provide a significant portion of services in many programs and agencies. The exact type of assistive technology services which can be effectively provided by volunteers requires additional investigation. Issues raised which also require further research are liability and quality assurance concerns.

Although volunteers represent an attractive alternative method of service delivery, there are costs associated with operating an effective volunteer program. The following observations were also noted in reviewing the survey responses:

- ▲ Most programs responding provide some training for volunteers.
- ▲ With the exception of Tech Act programs, most do not reimburse volunteers for expenses
- ▲ Travel considerations and other mobility restrictions may be limiting factors for consumer volunteers
- ▲ Significantly fewer retired persons (14%) were used as volunteers in Tech Act programs
- ▲ Coordinators (paid staff) were identified as being very important to successful volunteer programs
- ▲ Limited funds were cited as primary reasons for many programs to consider use of volunteers
- ▲ Concerns for liability were noted with recommendations made to consider obtaining insurance coverage

## SUMMARY

In comparing volunteers to consumer volunteers, few differences surfaced in the service areas in which they're used. One area of difference occurs in the area of qualifications. Consumer volunteers were expected to know or have experience with assistive technology.

Consumers are being used in a full range of capacities related to assistive technology services. Information and referral and advocacy activities were noted as primary areas. Limited involvement was noted in design and fabrication and other more technical activities. It is felt that consumers are capable of playing key roles in these capacities as well, particularly the design area. It was surprising to note that funding assistive technology ranked as a less frequently used role for volunteers.

Volunteers are being utilized to provide a significant portion of assistive technology services in many programs. Utilizing consumers in volunteer capacities is being done and represents one way to increase meaningful consumer involvement.

## ACKNOWLEDGMENTS

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Anthony J. Langton
Center for Rehabilitation Technology Services
South Carolina Vocational Rehabilitation Department
1410-C Boston Avenue
West Columbia, SC 29171-0015

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# Acceptance of Rehabilitation Engineering : A Survey of Healthcare Administrators

Lydia S. Gaster and James C. Gaster
Center for Rehabilitation Technology Services

## Abstract

There has been much speculation concerning the value of assistive technology services to medically based rehabilitation programs. However, the lack of widespread support from administrators of rehabilitation hospitals continues to be a deterrent to the acceptance of assistive technology as a separate, viable service. This paper attempts to examine the current attitudes and policies of these administrators by presenting results of a recent survey related to this issue. A discussion of the results in terms of future research and planning needs is provided.

## Background

During the past decade, there has been an explosion in the development of medically based rehabilitation programs. Many large medical systems have expanded services to include rehabilitation programs as an effort to increase profit and compete for commercial insurance dollars. There have also been many entrepreneurs venturing into the field of rehabilitation. Some of these programs offer limited, specialized services but most have ventured into comprehensive rehabilitation services.

A comprehensive rehabilitation program is defined as a program of coordinated and integrated services which include evaluation and treatment and emphasizes education and training of those served and their families. The program is applicable to those individuals who have severe disabling impairments of recent progression, those being readmitted, or persons who have not had prior exposure to rehabilitation (CARF, 1991). There may be many smaller specialized services or programs within these comprehensive programs. However, the majority do not offer assistive technology as a separate specialized service. One statistic that points to this fact is the low number of rehabilitation engineers working in medical based programs. In a recent survey of the members of RESNA's rehabilitation engineering professional specialty group, only 26 of the 184 respondents indicated that they work in a hospital setting (Trachtman, 1990).

The reasons for the lack of availability of rehabilitation engineering services are numerous and complex. One large underlying factor relates to the financial pressures placed upon administrators to provide intensive rehabilitation services in a cost effective environment. It has been speculated that many administrators are fearful that rehabilitation engineering services will add to operating costs and, at best, will result in uncollectible revenue (Laenger, 1987).

In order for the field of assistive technology to adequately address these issues, the attitudes and perceptions of rehabilitation hospital administrators must be clearly understood. This project has attempted to document current thinking concerning some of these critical issues through a nationwide survey of administrators.

## Objective

The survey was specifically developed to extract administrator's views concerning cost/benefit issues related to the provision of these services within their own facilities. The survey instrument was designed to document attitudes of administrators currently employing rehabilitation engineers as well as those who do not. The data gathered is to be used as a springboard to facilitate further research and development related to this pressing service delivery issue.

## Method

A mail survey was initiated in 49 states. The targeted population was selected by choosing CARF accredited rehabilitation programs designated as comprehensive inpatient rehabilitation programs, spinal cord injury programs, or brain injury programs. Since many of these facilities held accreditation under two or more of these designations, cross referencing was done to eliminate duplication. A decision was made to survey all programs rather than using a random sampling technique. The total number of programs surveyed was 407.

The survey packet contained a cover letter, a page defining assistive technology and rehabilitation engineering, a sheet requesting background information about the program, and a survey form. The survey instrument contained two major sections. The first section was composed of questions requiring respondents to rank items from the most important to the least important as they impact upon decision making. The second section contained Likert-type items constructed to obtain opinions on the possible impact rehabilitation engineering services would make on critical business issues such as payor mix.

## Results

A total of 159 surveys were returned, 5 of which were eliminated from the analysis because they were incomplete. Of the 154 surveys analyzed, 26 were from programs employing rehabilitation engineers. The respondents represent medically based rehabilitation programs from 41 states.

Questions 1 and 2 required respondents to rank in order from most important (1) to least important (4), factors that influence purchase of high tech aids or devices for the facility (Question 1) and employment of a rehabilitation engineer (Question 2). Weighted averages were used to depict an overall ranking. The respondents as a whole indicated that the ability to enhance the functional outcome of existing chargeable activities was the most important reason for purchasing equipment and employing rehabilitation engineers. However after separating respondents into two groups, those with rehabilitation engineers and those without, the second group indicated that employment of a rehabilitation engineer would be influenced by his or her ability to generate additional revenue. (See Figure 1)

## Acceptance of Rehabilitation Engineering:

### Question 2

**Items that were ranked from most important (1) least important (4)**

| | Engineer | No Engineer |
|---|---|---|
| Ability to generate additional chargable activities/revenue | 3 | 1 |
| Enhance functional outcome of existing chargable activities | 1 | 3 |
| Market new services to attract commercial payors | 2 | 2 |
| Physician support | 4 | 4 |

Figure 1

Question 3 required respondents to indicate to what extent the revenue produced by a rehabilitation engineering program offsets or would offset associated operating expenses. Respondents were asked to indicate on a 1 to 5 scale, 1 being loss, 3 the break even point, and 5 indicating profit. There were little to no differences between the responses of programs employing rehabilitation engineers versus those not employing engineers. Among all respondents, 38% indicated they felt there would be some loss, 40% indicated break even, and only 20% felt there would be some amount of profit.

### Profitability Question 3

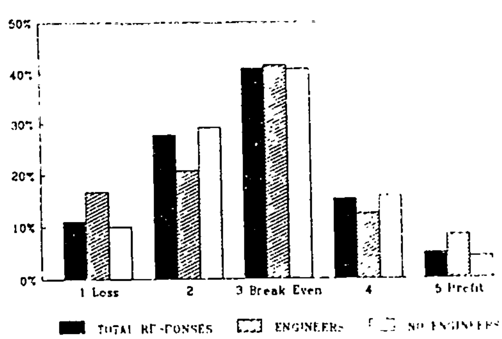


Figure 2

Questions 4 through 8 asked respondents to indicate the amount of impact they felt rehabilitation engineering services would have on various factors such as competitiveness (Question 4), functional outcome data (Question 5), length of stay (Question 6), speed of discharge placement (Question 7), and negotiation of higher per diem rates (Question 8). Respondents were required to indicate their opinion by choosing a point on a 1 to 5 scale, 1 indicating no impact, 3 indicating moderate impact, and 5 significant impact.

When separating respondents into the two previously mentioned groups, little difference was noted in administrators opinions. One exception relates to the issue of competitiveness. Of the administrators employing rehab engineers, 37% felt this service made a significant difference in their ability to compete with other rehab service providers in their region. Only 8% of administrators not employing rehabilitation engineers predicted that it would make a significant impact.

### Impact on Competition Question 4

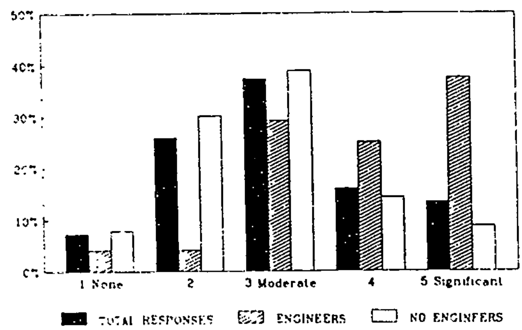


Figure 3

When looking at the respondents as a whole, another important trend was noted. Among all respondents, 59% felt that rehabilitation engineering services would make little to no impact on a program's ability to negotiate higher per diem rates for commercially insured patients (Figure 4). This is somewhat surprising considering the fact that many rehabilitation hospitals and outpatient programs are now carefully predicting the scope of services a patient will need before accepting him or her into their program. This information is then provided to case managers as an estimate on which to negotiate daily reimbursement rates for patient care.

### Impact on Per Diem Question 8

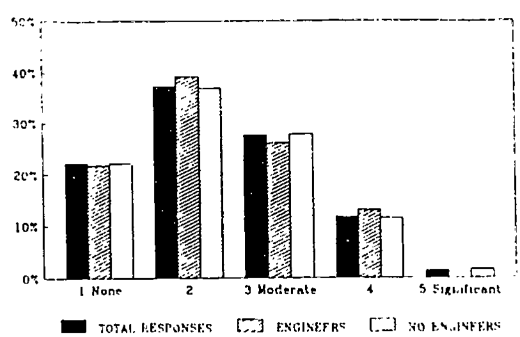


Figure 4

Possibly the most informative data gathered through the survey was the additional comments written by the respondents. Many respondents indicated on the background data sheet that services such as specialized seating, mobility, environmental control, augmentative communication, and worksite modifications were being provided through existing therapy staff. Another comment that appeared on many surveys was that insurers and third party payors are not interested in the depth of services provided to patients, rather they are concerned with cost containment.

## Implications

Several conclusions may be drawn from the information obtained in this study. First of all, assistive technology professionals must creatively demonstrate the ability to generate sufficient revenue. Since rehabilitation engineering services are not recognized by prospective payment systems, the professionals providing these services must seek innovative avenues of funding. The days are over when administrators can be convinced to pioneer new services where cost effectiveness is questionable. If assistive technology professionals are to be given a chance in the healthcare arena, they must approach it through strategic planning. A keen understanding of the healthcare business is equally as important as maintaining good clinical skills.

In reviewing the literature related to assistive technology and rehabilitation engineering, there continues to be very little hard data to substantiate or refute the views of administrators. Studies are needed that track and document revenue and costs within existing programs. A comprehensive look at present and future trends within the insurance industry should be made. Although the majority of respondents in the survey felt that offering rehabilitation engineering services would not increase per diems, there is no documentation available to back up this claim. Therefore assistive technology professionals should utilize this strategy where appropriate and document the results.

One important point should be stressed. Assistive technology professionals have the opportunity to take advantage of the competitive nature of the healthcare industry. This may provide the only door in which to enter and establish a much needed service. However, the survival and future of that service will depend on the ability of the profession to creatively demonstrate how assistive technology can be integrated into health care.

## Acknowledgments

The Center for Rehabilitation Technology Services, part of the South Carolina Vocational Rehabilitation Department, is a rehabilitation engineering center supported by the National Institute on Disability and Rehabilitation Research #G0087C0224-91.

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# Applied Study: A Model for Interdisciplinary Graduate Student Education and Design of Assistive Devices

James A. Lenker and Nigel Shapcott
Center for Therapeutic Applications of Technology
University at Buffalo
Buffalo, NY

## ABSTRACT

The Applied Study Project is developing and implementing a model that:

1. Supports graduate and professional education in assistive technology;
2. Augments assistive technology service delivery by increasing the production of assistive devices for specific individual needs.

Applied Study is an interdisciplinary project that involves graduate students and faculty representing the Departments of Occupational Therapy, Physical Therapy, Rehabilitation Nursing, Architecture and Design, Rehabilitation Counseling, Communicative Disorders and Sciences, and Engineering.

## BACKGROUND

Growth and development of the rehabilitation technology field relies on the expertise of a number of disciplines, including occupational and physical therapy, engineering, medicine, rehabilitation counseling, speech-language pathology, special education, and architecture. To quote Vroman, Croce et al. [8], "If the consumer is to receive maximal benefit from the various aspects of rehabilitation technology, those aspects must be effective and, more importantly, coordinated."

There have been a number of transdisciplinary models of coordinated rehabilitation technology service delivery that have been reported in recent literature [1, 3-8]. The individual models have included various combinations of the following general objectives:

1. Graduate education and/or professional training in rehabilitation technology service delivery.

2. Production of custom assistive devices for individuals whose needs are not met by available products or funding sources.

3. Research and development of new devices that have marketable potential.

4. Information dissemination for the purpose of model replication.

The settings and disciplines involved in each project have been varied and include:

- university-based service delivery: undergraduate industrial and biomedical engineering students with clinical supervision from occupational therapists, physicians, psychologists, and technicians supervising [1];
- hospital-based training and service delivery: biomedical engineer, speech pathologist, occupational therapist, occupational therapy assistant [3];
- university-based training: graduate and professional training for engineers, rehabilitation counselors, therapists and educators [4];
- university-based training and service delivery: graduate training for engineers and rehabilitation counselors [5];
- university-based training and service delivery: undergraduate bioengineering and special education [6];
- university-based training and service delivery: engineers and special educators [7];
- university-based training and service delivery: electrical engineer, occupational therapist, physiologist, and biomechanist [8].

The Applied Study Project, which began in September 1990, is developing and implementing a model that supports graduate and professional education in assistive technology, and augments assistive technology service delivery by increasing the production of assistive devices for specific individual needs. It is an interdisciplinary project involving graduate students and faculty representing the Departments of Occupational Therapy, Physical Therapy, Rehabilitation Nursing, Architecture and Design, Rehabilitation Counseling, Communicative Disorders and Sciences, and Engineering.

## OBJECTIVES

The goal of the Applied Study project is to develop and implement a model to increase the availability of assistive devices through a process that includes graduate and professional education. These broad goals are being attained by addressing five specific objectives:

1. Identification of persons in need of assistive devices.

2. Development of a system for producing assistive devices through the project seminar.

3. Organization of resources to produce assistive devices.

4. Transdisciplinary graduate education in assistive device design and service delivery.

5. Model dissemination.

## METHODS

Similar to [3], [5], and [6], the Applied Study model utilizes four educational modalities:

1. Traditional classroom
2. Faculty mentorship
3. Collaboration between graduate students

4. Independent investigation and development

Student involvement in Applied Study includes a three credit-hour assistive technology course, a one credit-hour seminar that meets bi-weekly, and a 20 hour per week research assistantship. Several of the faculty collaborate to teach the assistive technology course, and all participate in the bi-weekly seminars and individual student advisement.

The assistive device development component of Applied Study is accomplished through the bi-weekly seminar and the students' 20 hour per week research assistantship. Initial referrals documenting individual need are submitted to the project faculty, who meet and prioritize the referrals. Faculty present selected projects to the graduate students during the bi-weekly seminar and make project assignments based on student expertise and interest.

Teams of 2-3 faculty function as project mentors, and all faculty and students share suggestions and problems encountered during the bi-weekly seminars. The projects have five reporting milestones, including initial oral, initial written, intermediate oral, intermediate written, and final oral. These steps help project leaders establish a systematic approach to assessment, problem definition, solution formulation, fabrication and follow-up. Technical fabrication expertise is available from three mechanical shop technicians, two electronics technicians, and one electronics engineer.

RESULTS

After fifteen months there have been 9 devices designed and fabricated for use by individuals with disabilities, 5 off-the-shelf devices have been recommended and purchased for clients, and 4 devices have been made for general clinical application. Three of the devices have potential for commercial development or widespread clinical application: a portable vacuum pump for extended trial assessment of "bead" seating systems, a power wheelchair simulator, and a bar code-programmable microwave oven.

Students have been encouraged to use their projects as a basis for their graduate theses; so far four have done or will be doing their thesis on their Applied Study project.

As one would expect, though, there have been several kinks in the model.

1. Initially, students had limited knowledge of the expertise that could be contributed by students and faculty from other disciplines. This is similar to the findings of Clipson [2], who was directing an interdisciplinary group of faculty and graduate students from business, product design, graphic design, architecture and engineering. A multi-day student orientation was given at the beginning of Year 2 to alleviate this problem.

2. Some students had difficulty getting started on their projects and seemed to flounder because of the open-ended nature of their assignments. This seems to reflect the lack of experience that the students have in independent project management. As phrased by Clipson [2], "Much of educational experience is not experimental, but involves being told what to do and when to do it." It makes sense that students, even at the graduate level, would have difficulty making the transition to a project whose expected outcome is a tangible, functional, user-appropriate device. To address this issue, 2-3 faculty mentors were assigned to each student project. It is anticipated that the students will feel more "directed" because of the individualized faculty attention outside of the bi-weekly seminar. It should also help increase faculty awareness of the subtler issues in each project.

3. Some students experienced "down time" on their projects and were idle while waiting for product literature, parts, or other essential information. Initially there was no mechanism for keeping them busy during idle periods. After faculty discussion it was decided that students who were "on hold" would be temporarily directed to assist with another project. This solution also provided greater opportunity for student collaboration.

4. The most critical phase of any rehabilitation technology project is during initial assessment and problem definition. Given the number of project participants and the diversity of their schedules, it was extremely difficult for more than two persons to participate in any given initial on-site assessment. Without having seen the client and his or her environment firsthand, it was harder for faculty and students to contribute meaningful suggestions to the project leaders during the bi-weekly seminars. Several students secured proper client consent and videotaped their assessments. The visual information provided by the tapes was extremely valuable. It enabled all participants to feel as if they were a part of the assessment process, and it improved the quality of suggestions that the participants were able to provide.

5. Group problem-solving and brainstorming occurs during the bi-weekly seminar sessions. These were initially scheduled to occur for one hour every week, but it was soon apparent that there wasn't enough time to discuss all projects thoroughly. Beginning in the second semester of Year 1, the seminar began meeting for two hours every other week. This was a much more relaxed and effective format because it allowed ample time for project discussion.

6. The process of sharing their expertise with one another has not come easily for the graduate students (Predictably, this hasn't been a problem for participating faculty!). During the bi-weekly seminars, some students were understandably hesitant to express their ideas in front of all eight project faculty members. An inherent mechanism is needed to encourage greater student collaboration on assigned projects, but this is a difficult personnel management task for two reasons:

i. All students need a primary project for which they are the project leader.

ii. Project leaders require collaboration with others for only limited periods of time during their projects. For example, an engineer might need the consult of a rehabilitation counselor and a therapist for the assessment and problem definition phase of the project, require an architect's assistance during the design and fabrication phase, and then require a therapist's assistance for fitting and follow-up. These time-limited windows of need are very difficult to coordinate if the required "expert" is buried in the responsibilities of his or her own project.

## DISCUSSION

The Applied Study project touches on a number of facets of rehabilitation technology: service delivery, basic research, product development, and professional training.

Pertaining to device research and development, the transdisciplinary team model implies that service delivery is improved through better communication and coordination between contributing disciplines. The team approach is essential for addressing the complexity of needs presented by most of the projects. The Applied Study group is producing excellent product results, and this is due to the quality of the personnel and the diversity of their collective experiences.
The contributions of the rehabilitation counseling student and faculty member have been invaluable for proper consideration of user-acceptance issues

In terms of education and training, the key to students learning more about fields outside their own lies in working on real problems with experts from other fields. One of the strengths of the Applied Study model is the ability of the participating faculty to demonstrate that the experiences of a specific project are generalizable to situations that might be encountered in future practice.

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James A. Lenker
Center for Therapeutic Applications of Technology
University at Buffalo
515 Kimball Tower
Buffalo, NY 14214

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# KINEMATIC AND KINETIC RESPONSES TO WHEELCHAIR PROPULSION DURING FATIGUE IN SCI INDIVIDUALS A PILOT STUDY

M.M. Rodgers, G.W. Gayle, S.F. Figoni, M. Kobayashi*, R.M. Glaser, & S.C. Gupta
Veterans Affairs Medical Center; Institute for Rehabilitation Research & Medicine, Wright State University, Dayton, OH;
*Laboratory of Sports Science, Nihon Fukushi University, Mihama, Japan

## ABSTRACT

The purpose of this pilot study was to determine how wheelchair biomechanics change with fatigue to identify potential injury-causing characteristics. Eleven non-athletic spinal cord injured (SCI) male subjects were videotaped during propulsion to fatigue on a stationary, instrumented wheelchair positioned on a roller. Handrim force and cycle times (contact and recovery) were also recorded. Videotaped movements were analyzed using a computerized three-dimensional motion analysis system. With fatigue, shoulder flexion decreased and trunk inclination range increased significantly. Minimal changes were seen in mean shoulder abduction, elbow and wrist ranges. Handrim force increased by 3% and contact time decreased slightly with fatigue. The kinematic and kinetic changes with fatigue were variable among subjects indicating that some individuals may be more prone to musculoskeletal injury. Therefore, these biomechanical techniques may be applied clinically to improving propulsion techniques, wheelchair design/prescription, and therapeutic intervention to decrease orthopedic risks.

## INTRODUCTION

Chronic health problems due to long-term use of manual wheelchairs significantly impair the independence of wheelchair-dependent spinal cord injured (SCI) individuals. Although many of these health problems are musculoskeletal injuries (i.e., carpal tunnel syndrome, elbow/shoulder tendonitis) which have been documented in wheelchair athletes (1), they are probably related to the constant repetitive movements which occur with everyday wheelchair propulsion (e.g., overuse injuries). It is also feasible that orthopedic problems can arise from malalignment of the limbs which may occur with fatigue or inappropriate wheelchair design/prescription. The use of biomechanical techniques may provide better understanding of those factors which relate to wheelchair user injuries.

The few studies which have included descriptions of wheelchair propulsion biomechanics have included only those movements occurring in one plane, neglecting the three-dimensional aspects of the arm movements such as shoulder abduction (2,3). In addition, most investigators have utilized wheelchair athletes as subjects, and excluded individuals from the general wheelchair user population. Although these studies have provided important information, there is a need to study the three-dimensional aspects of wheelchair propulsion in the general SCI population.

The purpose of this pilot study was to apply three-dimensional kinematic analysis, as well as kinetic measurements to the investigation of wheelchair propulsion biomechanics of non-athletic SCI wheelchair users. In addition, we studied changes in these variables that occur with fatiguing wheelchair propulsion.

## METHODS

Eleven male paraplegics with spinal cord lesions between $T_5$ and $T_{11}$ participated in this pilot investigation. Following informed consent procedures, medical screening was performed to eliminate those individuals with contraindications to exercise. Physical characteristics were obtained from each individual which included anthropometric measurements, upper-body isokinetic muscle strength evaluation (KinCom, Chattecx Corp., Chattanooga, TN), and neuromuscular assessments.

A wheelchair instrumented with strain gauges for measuring handrim force and duration of hand contact (2) was positioned on rollers to enable stationary propulsion. Figure 1 diagrammatically illustrates the stationary wheelchair exercise device. Exercise intensity was varied by changing the resistance weight which applied frictional force

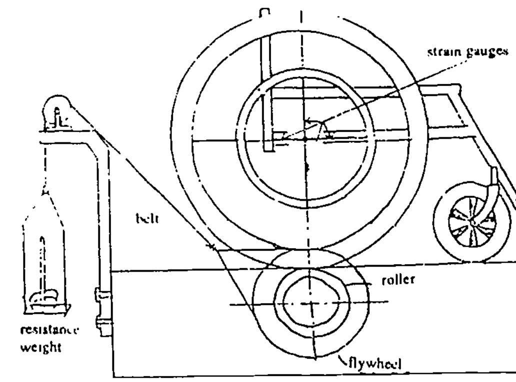


Figure 1. Diagrammatic illustration of the specially instrumented wheelchair mounted upon a roller for stationary operation. The intensity of exercise can be set by varying the resistance weight to alter the braking friction applied to the flywheel via the nylon belt.

to the roller via a nylon belt. Each subject performed two wheelchair roller exercise tests on separate days. The first was a continuous, progressive intensity exercise test for determination of peak physiologic (i.e., metabolic and cardiopulmonary) responses. The second was a fatigue test consisting of propulsion for 6 minutes at a load corresponding to the 50% peak oxygen uptake ($\dot{V}O_2$) level for warm-up, followed by a step increase in power output to elicit 75% peak $\dot{V}O_2$ level until volitional fatigue was achieved. Heart rate and $\dot{V}O_2$ were monitored continuously during each test using a metabolic cart and radiotelemetry ECG.

Movement was videotaped using a three-dimensional motion analysis system (Peak Performance Technologies, Inc., Englewood, CO). Reflective markers placed on joint centers of the subjects' wrist, elbow, shoulder and hip. In addition, a marker was placed upon the wheelchair wheel to monitor rotation angle. These marker locations were computer digitized from the videotape to produce kinematic data (Figure 2).

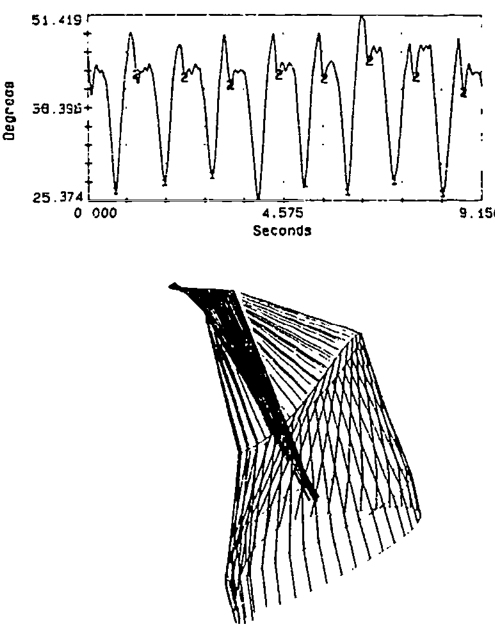


Figure 2. The stick figure is reconstructed from reflective marker locations on a subject and shows the movement of the upper extremity during wheelchair propulsion. The abduction of the shoulder, a movement which requires three-dimensional motion analysis, is shown in the lower graph.

Five handrim strokes for the right hand of each subject were averaged for the first ("non-fatigued") and final ("fatigued") conditions during the fatigue exercise test. Handrim force was monitored via computer at 2-minute intervals during each test to provide kinetic and temporal information.

Statistical analysis was performed using analysis of variance with repeated measures (time factor). A significance level of .05 was used for all comparisons.

## RESULTS AND DISCUSSION

Subjects were ($\bar{x} \pm SD$) 35.6±10.9 years of age, 177.4±9.1 cm in height, 77.5±13.1 kg weight, and 11.2±7.0 years post SCI. All eleven subjects completed both exercise tests demonstrating that protocols were appropriate for evaluating physiologic responses and fatigue characteristics for wheelchair propulsion. Mean peak $\dot{V}O_2$ was found to be 1.45±0.42 L/min during the first exercise test. Thus, the resistance weight was adjusted to provide wheelchair loading that elicited $\dot{V}O_2$ levels of 0.72±0.25 L/min and 1.10±0.33 L/min for 50% peak and 75% peak, respectively.

For the second exercise test, mean joint ranges of motion for the non-fatigued and fatigued conditions are shown in Table 1. With fatigue, maximum shoulder flexion decreased significantly (by 25%) and trunk inclination (as measured from trunk extension) increased significantly (by 30%). Minor fatigue changes were seen in shoulder abduction (3% increase), elbow flexion/extension (2% increase), wrist flexion/ extension (5% decrease) and radial/ulnar deviation (5% decrease).

TABLE 1 - Mean ± SD joint angle ranges (in degrees) in the non-fatigued and fatigued conditions (N = 11)

| JOINT MOVEMENT | JOINT ANGLE RANGES (degrees) Non-Fatigued | Fatigued |
|---|---|---|
| Shoulder flexion/extension | 66.0±5.5 | 67.7±6.3 |
| Shoulder abduction | 20.0±5.2 | 20.8±4.9 |
| Elbow flexion/extension | 58.2±9.9 | 59.4±10.2 |
| Wrist flexion/extension | 41.0±9.0 | 38.7±8.0 |
| Ulnar/radial deviation | 72.4±13.1 | 68.4±10.1 |
| Trunk inclination* | 7.8±3.6 | 12.4±6.8 |

*p<.05

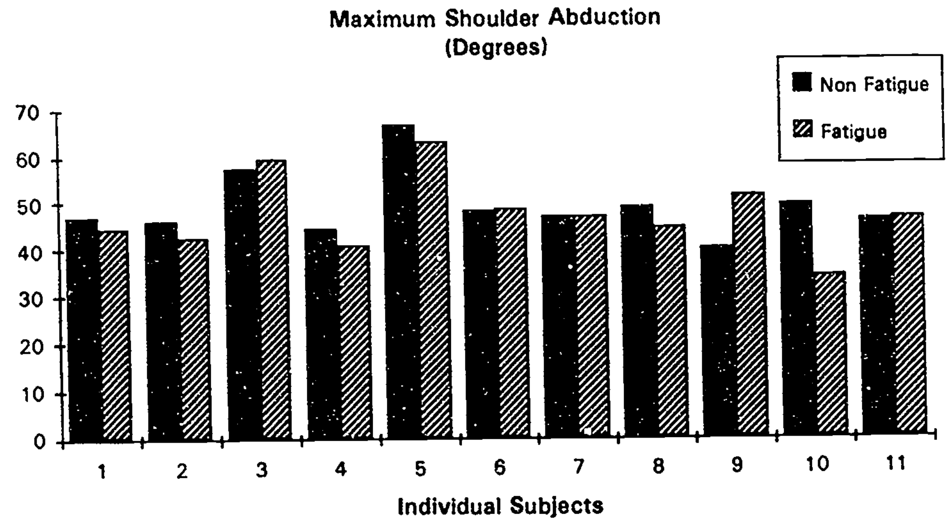


Figure 3. Maximum shoulder abduction measurements (in degrees) for 11 SCI males in the non-fatigued and fatigued conditions.

Marked variability in kinematic data was evident in individual fatigue patterns. As an example of this variability, Figure 3 shows the shoulder abduction measurements for each subject during the non-fatigued and fatigued conditions. Maximum shoulder abduction increased with fatigue for five subjects, and decreased for six subjects. The reason(s) for this variability seen with fatigue is currently unclear. It is conceivable that this may be due in part to differences in physical characteristics since they all propelled the same wheelchair for testing. This variability may also be related to individual differences in propulsion style, as well as any imbalances in muscle strength. The magnitude of shoulder abduction evident in the analysis highlights the importance of utilizing three-dimensional analysis.

Fatigue also resulted in slight kinetic changes as evidenced by the 3% increase in mean handrim force from $107.7 \pm 6.4$ to $110.5 \pm 8.3$ N. Temporal changes were also minimal as shown by the similar non-fatigued and fatigued mean handrim stroke cycle times ($129.3 \pm 8.3$ vs $124.9 \pm 5.7$ msec), duration of contact times ($91.2 \pm 7.4$ vs $87.8 \pm 4.0$ msec) and recovery times ($38.1 \pm 7.4$ vs $37.1 \pm 5.2$ msec).

None of the non-fatigued/fatigued comparisons were statistically significant. This lack of statistical significance is probably caused by the small sample size used for this pilot study and marked variability among subjects. The variety of angular and force changes seen may indicate individualized patterns of fatigue during wheelchair propulsion.

Identification of kinematic and kinetic factors during wheelchair propulsion which change with fatigue provides the necessary foundation for optimizing wheelchair function and safety. These techniques may be clinically applied to improve propulsion techniques, wheelchair design/prescription, and therapeutic intervention. This may decrease the risk of orthopedic injuries in SCI wheelchair users and increase their rehabilitation potential.

ACKNOWLEDGEMENTS
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Mary Rodgers, Ph.D., P.T.
VA Medical Center (151)
4100 West Third Street
Dayton, OH 45428

# The Physiological Response to Repeated Surface Pressure Loads in the Able Bodied and Spinal Cord Injured

R. Patterson, H. Cranmer, S. Fisher* and R. Engel*
University of Minnesota and Hennipen County Medical Center*
Minneapolis, MN

**Abstract**

Three cyclic pressure loads (10 min. "on and 5 min "off") of 30 mmHg or 75 mmHg were applied to the anterior surface of the tibia on 11 able bodied (AB) and 9 spinal cord injured (SCI) subjects. Transcutaneous $PO_2$ and $PCO_2$ and laser doppler skin blood flow, velocity and volume were recorded. At the 30 mmHg load, the mean $PO_2$ values in the AB subjects was 28.4 and 32.2 mmHg for the on and off periods respectively, whereas for the SCI subjects the values were 8.1 (significantly different from AB group at $P<.05$) and 29.1 mmHg for the on and off periods respectively. At the 30 mmHg load the laser doppler relative volume values in the AB subjects were 31.2 and 49.2 for the on and off periods respectively whereas for the SCI subjects the values were 10.9 and 29.1 for the on and off periods respectively. The results at the of 75 mmHg load showed no significant difference between the two groups but the means did reflect less perfusion in the SCI group. In the 30 mmHg pressure load range where autoregulation may occur, the SCI had significantly less perfusion on the average compared to the AB.

## Introduction

The purpose of this study was address two questions. Does the spinal cord injured (SCI) individual respond differently to a pressure load on the skin compared to the able bodied (AB) and is the response to repeated skin pressure loadings different than a single continuous load?

Bader(1) measured transcutaneous oxygen pressure ($T_cPO_2$) and carbon dioxide ($T_cPCO_2$)in a group of " debilitated" subjects, which included SCI, multiple sclerosis, and AB subjects during repeated pressure loads on the sacrum and ischial tuberosities. His results indicated the $T_cPO_2$ levels during the loading period increased in the AB subjects with repeated loads whereas with some of the debilitated subjects the $T_cPO_2$ decreased. His study was performed on a small group of subjects with a mixture of medical conditions.

The purpose of this study is to compare the changes in $T_cPO_2$ , $T_cPCO_2$ and laser doppler skin blood flow in a group of AB and SCI individuals undergoing repeated surface pressure loadings of 30 and 75 mmHg on the anterior tibial surface of each leg.

## Methods and Materials

The $T_cPO_2$, $T_cPCO_2$, and power were measured using Sensor Medics Transcutaneous Gas System. The skin blood flow, volume and velocity were recorded with a TSI Laserflo, model BPM-403, in conjunction with a TSI Pencil Probe, model P-435. The temperature of each probe was maintained at 40 °C. This temperature is lower than the normal clinical 43 to 44 °C range used to record arterial $PO_2$. The higher temperature is used to maximally dilate the arterial system in order to obtain values as near as possible to arterial. In this study, we wish to measure tissue $PO_2$ and to observe the effects of arterial dilation that may be caused by the ischemia therefore a lower temperature was used. All data were monitored and recorded using CODAS A/D software and hardware on an IBM compatible computer.

A vertical load was applied to the flat ventral tibial surface of each leg using a balanced beam with a moveable weight on one end to counterbalance the indentor. Weights were added to the top of the indentor to produce a pressure of either 30 mmHg or 75 mmHg at the surface of the skin. The tibial surface was used because it simulated an area that could develop pressure sores, i.e., bony with little soft tissue mass. The leg site was much more agreeable to the subjects as compared to the less accessible ischial tuberosity area, and it would not irritate an otherwise vulnerable region with any excess stresses.

Two 55 min. trials were conducted. For the first trial a pressure load of 30 mmHg was used and for the second trial 75 mmHg. For each trial, there was an initial warm-up period of 10 minutes which adapted the skin to the temperature of the sensor, then three cycles of sequential loading "on" for 10 min. and unloading "off" for 5 min.

Continuous recording took place for the 15 seconds preceding and the 45 seconds following the load transition. The 'pre-load' values were measured ten minutes after the sensors were positioned. The reported means were calculated from the last 10 seconds of each experimental condition and represent "steady-state" measurements.

Measurements were made with the subjects supine. The skin was prepared by shaving an area of approximately 2.5 cm by 2.5 cm, located about 12 cm distal to the patella. To position the leg with the flat tibial surface in the horizontal plane, the legs were supported at the knee and ankle using rolled-up towels. The sensors were attached to the skin using double-sided adhesive rings.

Measurements were made on 11 AB healthy subjects, five of whom were women, and 9 SCI subjects, all men. The SCI subjects were paralyzed at T6 or above for at least one year prior to the test, and all but two had no recent pressure sores. Those with sores reported minor wounds, on the verge of healing. The average ages of the SCI persons and AB subjects were 27 and 34, respectively.

**Results**

Two sets of statistical analysis were performed to determine significant differences. The first comparison was between SCI subjects and AB subjects at each of the pressure settings. The second comparison was between the two loads for AB subjects and for SCI subjects. An ANOVA compared overall means for each set at each interval for each parameter.

The means of $TcPO_2$ at 30 mmHg load showed a statistically significant difference ($p < 0.05$) during the "on" period between AB ($PO_2$=28.42 mmHg) and SCI subjects ($PO_2$=8.10 mmHg) but no significant different during the "off" times ( AB $PO_2$= 32.8 mmHg and SCI $PO_2$= 29.1 mmHg) which is shown in fig. 1. During and after the 75 mmHg load shown in fig. 2, the AB group has an "on" value of 7.6 mmHg and an "off" value of 31.3 mmHg whereas under the same conditions for the SCI the values were 4.4 mmHg and 23.0 respectively. These values were not statistically significantly different. Comparison of the means of Laser Doppler volume values showed significant differences ($p < 0.05$) between the two subject groups at each pressure loading. Values for the Laser Doppler measurements have no units and are reported as relative numbers. At 30 mmHg, the average "on" volume means for AB and SCI subjects were 31.2 and 10.9, respectively. The average "off" means were 49.2 and 29.2. At 75 mmHg, the average "on" volume means for AB and SCI subjects were 20.5 and 1.3, respectively. The average "off" volume means were 45.4 and 23.9 respectively. For most parameters, there was an upward trend in the data after repeated loading cycles for both subject groups.

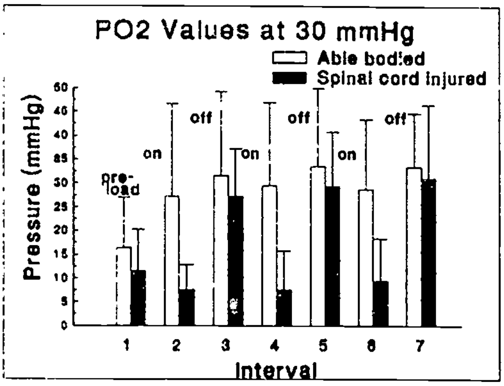


Figure 1 $TcPO_2$ values during repeated "on" and "off" 30 mmHg pressure loads for AB and SCI sujects.

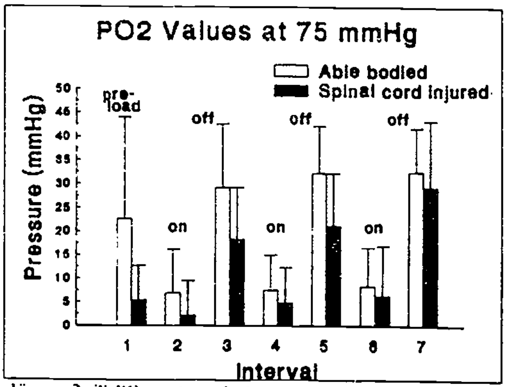


Figure 2. $TcPO_2$ values during repeated "on" and "off" 75 mmHg pressure loads for AB and SCI sujects.

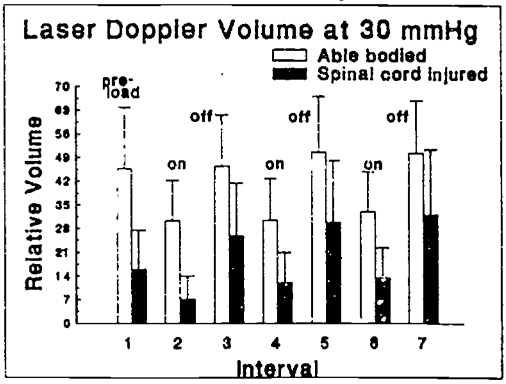


Figure 3. Laser doppler volume values during repeated "on" and "off" 30 mmHg pressure loads for AB and SCI subjects

**Discussion**

The results of this study suggest that in the 30 mmHg load region, the SCI subjects did not auto regulate and have the same tissue perfusion compared to the AB, therefore they had a significantly reduced tissue $PO_2$. At 75 mmHg there was little difference between the AB and SCI in the physiological response because the pressure is near or at the mean arterial pressure which causes a physical impedance to flow that can not be overcome with vasodilatation. These results agree with Bader(1) in that the SCI group had a different response compared to the AB group although we did not see the decreasing $PO_2$ values with repeated loadings reported by Bader(1) in some of his "debilitated" patient group subjects. The results of this study suggest on the average the SCI population does not autoregulate to increase perfusion compared to the AB group.

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Mailing Address: Robert Patterson, Ph.D.
University of Minnesota Hospital
UMHC Box 297
Minneapolis, MN 55455
612 626 3308

# THE EFFECT OF SAMPLING FREQUENCY ON SEAT CONTOUR REPRODUCTION FOR CAD/CAM SEATING SYSTEMS

David M. Brienza, Ph.D.
School of Health and Rehabilitation Science
University of Pittsburgh
Pittsburgh, Pennsylvania

## Abstract

The effect of sampling frequency on the reproducibility of seat contour data has been investigate. Buttock shape information was sampled at frequencies that are typical for CAD/CAM seat contour measurement systems. These data sets were used as control points for cubic spline interpolation. The resulting contours are compared to the original high resolution data and evaluated. The factors considered in the evaluation are the interpolation method, the alignment of the data with respect to the borders, and the spatial sampling frequency. Sampling frequency is determined to be the dominant factor effecting the fidelity of the reproduced contour. Insufficient sampling frequency results in the shifting or attenuation of contour features.

## Introduction

The primary purpose of this investigation is to examine the relationship between the spatial sampling frequency of seat and back contours and the ability to reproduce the contours from the sampled data. Two other variables in this process—the type of interpolating spline and the offset of the first sample with respect to the edge of the contour—have been considered. The sampling frequency is an important design specification for any seat or back contour measurement system. Minimizing the number of measurements will reduce the cost CAD/CAM measurement systems and/or reduce the time required for the measurement process. The results shown here should assist in the system design process or application protocols for CAD/CAM seating systems.

## Methods

The outline of an MRI image showing a cross section of the buttocks of an able-bodied male was used as the reference data for the analysis. The portion of the image representing the bottom 3 inches of the buttocks was sampled with a resolution of 0.1 inches in the horizontal and vertical directions. The MRI image is shown in Fig. 1. The data was then smoothed using a weighted averaging filter with an extent of 5 samples. The resulting data set is plotted in Fig. 2. The curvature of the particular contour is typical of seat and back contours of custom seating systems used for positioning and posture control. Pressure relief cushion contours would have less curvature.

The high resolution data was sampled along the horizontal direction at sampling intervals of 0.5, 1.0, 1.5, and 2.0 inches. For each sampling frequency a group of five data subsets were formed. The first set in each group started with the first sample at the left edge of the high resolution data—i.e., at the first sample. Each successive set was offset by one fifth of the distance between the samples. That is, for the 0.5 in. interval group, each successive data set was offset 0.1 in. For the 1.0 interval group, each successive data set was offset 0.2 in. and so on. Since each of these spacings are multiples of the original data resolution, no interpolation was necessary for this procedure.

The next step was to compute a cubic spline for each data set. A cubic spline is a piecewise polynomial that is twice continuously differentiable and in each interval between sample points the function is described by a third order polynomial [Ortega , 1981]. These properties make the cubic spline an attractive option for interpolation of sampled data of a smooth curve. The cubic spline technique can be extended for the interpolation of smooth surfaces. This is typically accomplished by fitting cubic splines along a rectangular grid of sample points and deriving surface patches for each rectangular section from the cubic polynomial boundary functions. The patches are often bilinearly or bicubically blended Coon's patches [Coon's, 1964, or Farin, 1988]. For this investigation, regularly spaced sample points along a planer curve are considered. However, the results should be applicable to any interpolation technique, two or three dimensional, with properties similar to those of the cubic spline.

Fig 1 - MRI image of the buttocks

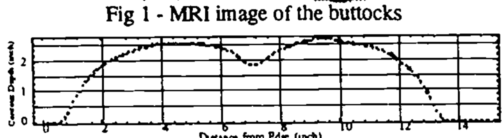

Fig 2 - Smoothed original data

Figure 3 is an illustration of the difference between cubic, quadratic and linear spline interpolation. In the figure, small segments of the interpolation curves derived from the first data set in the 1.5 inch sample frequency group are shown. The original data is shown in the lower portion the figure with the spline functions stacked above—offset from one another so that their shapes can be more easily viewed. The samples of the original data are taken at 9.0 and 10.5 inches from the edge of the contour. The value of each spline is exact at these points. Comparing the 2nd and 3rd order splines illustrates the benefit of having an interpolating spline function with continuous 2nd derivatives. The quadratic spline has a noticeable cusp at the first sample point caused by a discontinuous 2nd derivative at that point. The cubic spline has a smooth transition through this point. The linear spline is more easily computed, but would only be appropriate if the data samples were already very closely spaced. The fourth order spline takes on a slightly different shape than the cubic spline but does not provide better results.

## Results

To examine the effect of varying the sampling resolution, each spline is compared to the original data. The comparison is made qualitatively by comparing the shapes of the splines and the original data and quantitatively by computing the maximum and cumulative deviations. Table 1 shows the quantitative measurements and Figs. 4 through 8 show the qualitative information. In table 1 the maximum error is the largest difference between the value of the interpolating spline and the original high resolution data. The data was padded with zeros on both sides so that each set of data extended over the entire range of the contour. Also, the derivatives of the interpolating splines were constrained to zero at these points to reduce the ringing effect near the boundaries. The cumulative error is the sum of the difference between the value of the interpolating spline and the high resolution data sample at each of the sample point multiplied by the distance between the samples.

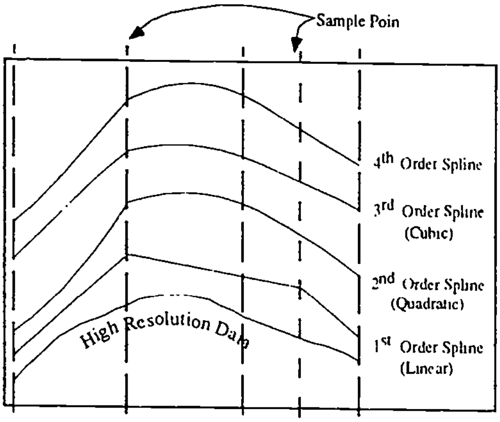


Fig. 3 - Comparison of Interpolation Methods

The magnitude of the maximum and cumulative error terms varies substantially for the groups with sampling frequencies greater than 0.5 in. This variation is a result of how well the data samples are aligned with the most prominent features of the contour. To compare the sampling frequencies, the average values for these quantities will be considered. In most practical measurement situations, the operators or systems do not have the luxury of optimally aligning the data samples with the prominent features of the shape being measured. Also, it is unlikely that multiple features could be optimally sampled using a regularly spaced sampling pattern. Figure 4 illustrates how the first sample offset effects the accuracy of the reproduced contour for the 2.0 in. sampling frequency group. Each plot in the figure represents the difference between the value of the interpolating spline and the high resolution data sample. This quantity is shown for the 5 different offsets ranging from 0 in. to 1.6 in. For this sampling frequency, how closely a sample point comes to the peak in the center of the contour has the most impact on the accuracy of the reproduced contour. Here, the zero offset data set places a point relatively near to this peak.

The maximum and cumulative error terms increased with the sampling frequency. The largest increase in ave. cum. error occurs between 1.0 and 1.5 samples per inch. To make a qualitative comparison, the data set with the lowest cumulative error from each group has been plotted along with the original data. These data sets are shown in boldface type in table 1 and plotted in Figs. 5 through 8. The 0.5 inch data did not show any significant error over the entire range of the curve. The 1.0, 1.5, and 2.0 inch data deviated from the original data at the edges and near the cusp in the center. The overall effect of this error is a shifting of the center of contour. This is significant because a feature similar to this in a seat surface will be used as a reference by the user. Any shift of this reference could have significant effects on other features of the contour. An example of such a feature is a depression for pressure relief that depends on a particular relative location in the interface. The magnitude of the shift could be up to 1/2 the sampling frequency.

| Frequency Sample/in | Offset (in.) | Max. Error (in.) | Ave. Max. Error (in.) | Cum. Error ($in.^2$) | Ave. Cum. Error ($in.^2$) |
|---|---|---|---|---|---|
| 0.5 | 0.0 | 0.11 | 0.09 | 0.17 | 0.14 |
| | 0.1 | 0.11 | | 0.15 | |
| | 0.2 | 0.07 | | 0.13 | |
| | **0.3** | **0.07** | | **0.12** | |
| | 0.4 | 0.10 | | 0.15 | |
| 1.0 | 0.0 | 0.31 | 0.33 | 0.72 | 0.61 |
| | 0.2 | 0.32 | | 0.60 | |
| | **0.4** | **0.22** | | **0.48** | |
| | 0.6 | 0.35 | | 0.54 | |
| | 0.8 | 0.47 | | 0.71 | |
| 1.5 | 0.0 | 0.47 | 0.45 | 1.08 | 1.32 |
| | **0.3** | **0.39** | | **1.02** | |
| | 0.6 | 0.53 | | 1.36 | |
| | 0.9 | 0.49 | | 1.45 | |
| | 1.2 | 0.36 | | 1.05 | |
| 2.0 | 0.0 | 0.37 | 0.53 | 2.02 | 1.79 |
| | 0.4 | 0.47 | | 1.60 | |
| | **0.8** | **0.47** | | **1.42** | |
| | 1.2 | 0.61 | | 1.75 | |
| | 1.6 | 0.72 | | 2.16 | |

Table 1 - Quantitative comparison of sampling frequencies

## Discussion

Since seat contours are formed in compliant materials, there is some room for error in the CAD/CAM process. However, the significance ot the error is dependent on, among other things, the intended use of the data, the tolerance of the manufacturing process and the accuracy of the measurement system. It is likely that the accuracy of the measurement and manufacturing systems will be better than the error caused by less than perfect sampling of the contour. The errors that cause the most significant problems are a shifting of features of the contour and the omission of features in the reproduction. In the results presented, the cusp in the center of the curve was not significantly attenuated until the sampling frequency exceeded 1.5 inches. A distinction must be made between contours designed for pressure relief and those designed for positioning and posture maintenance. Typically a pressure relief contour would be shallower and have less curvature than a positioning contour. As a result, a suitable sampling frequency could be lower. The data used for this study, although of comparable depth, has curvature that is greater than typical pressure relief seat contours.

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David M. Brienza, Ph.D.
915 William Pitt Way
Pittsburgh, PA 15238

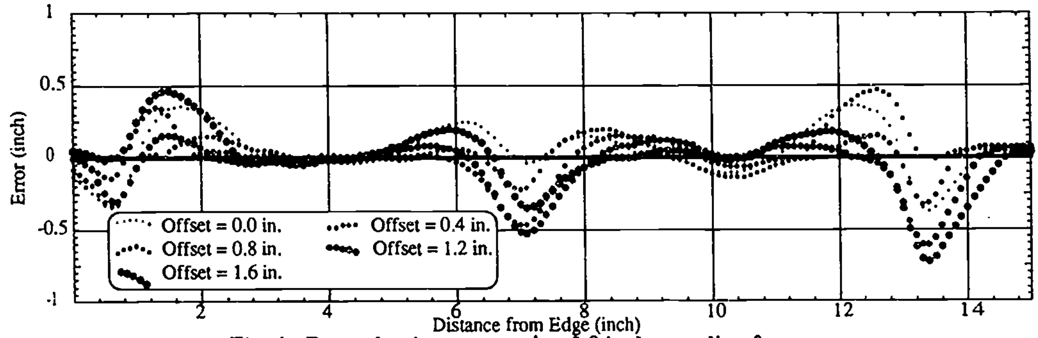


Fig. 4 - Reproduction error using 2.0 inch sampling frequency

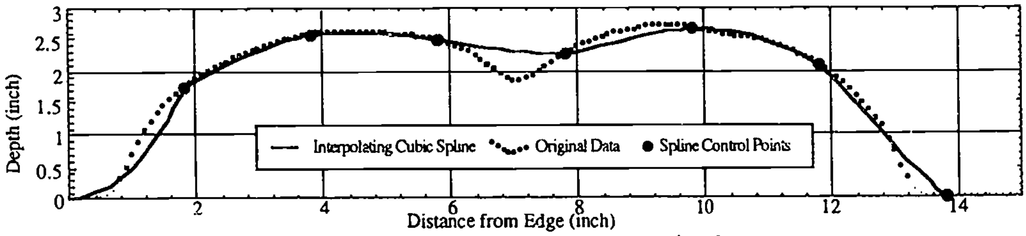


Fig. 5 - Interpolation using 2.0 inch sampling frequency

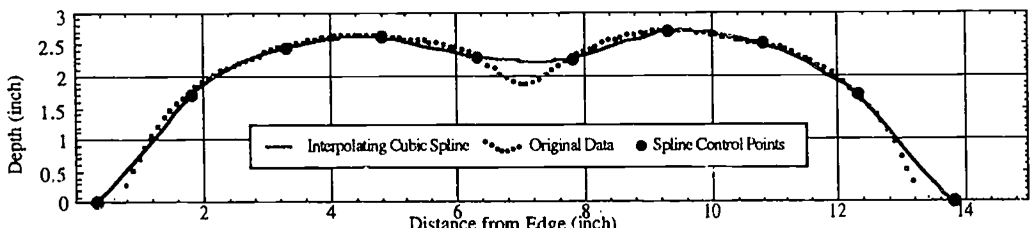


Fig. 6 - Interpolation using 1.5 inch sampling frequency

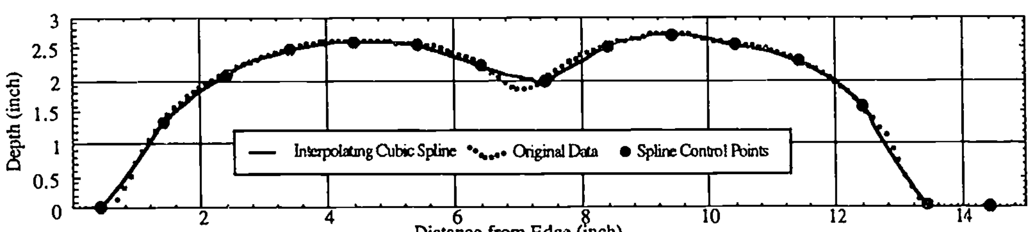


Fig. 7 - Interpolation using 1.0 inch sampling frequency

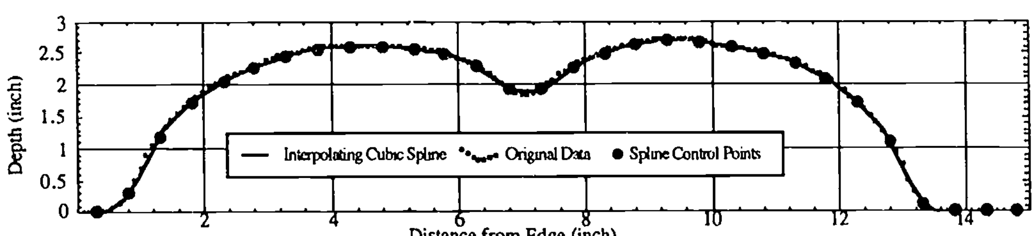


Fig. 8 - Interpolation using 0.5 inch sampling frequency

12.4 Characterization and Development of a Resistive Sensor for Measuring Cushion Interface Force

Rory Cooper, Colleen Ward, and James Ster III
Human Engineering Laboratory and Rehabilitation Engineering Program
Department of Biomedical Engineering
California State University, Sacramento

## ABSTRACT

Wheelchair cushion interface force has been of interest to researchers and clinicians. The ability to measure interface force may assist in the development of improved seating systems and their proper application. An inexpensive conductive polymer resistive force sensor was characterized, and then modified to be suitable for reliably measuring cushion interface force. It was found that the sensors behave nonlinearly, and are influenced by the compliance of the contact material. A simple method for encapsulating the sensor was developed to make it more repeatable.

## Background

There are over 300,000 people in the United States with spinal cord injuries, and this number is growing by about 7,000 people per year. Pressure sores are probably one of the most prevalent medical complications associated with spinal cord injury (Pope A.M., Tarlov A.R., 1991.). In developing countries, pressure sores are one of the leading causes of death among people with spinal cord injuries. Proper education and assistive technology can be effective in ameliorating this situation.

Several devices have been developed to measure cushion interface pressure (Ferguson-Pell, 1990). Most of these devices are used to measure static seating pressure. This assumes that the a wheelchair is a static device (which it is not), or that pressure changes do not vary dramatically during the day or during various activities (this is most likely not the case). Devices for measu.ing pressure can be useful in identifying localized areas of high pressure. However, the skin pressuie is lower than the interior pressure around bony prominences, where most ulcers begin.

Two recent innovations have developed that may dramatically improve cushion design and presciiption. The first is the development of low cost, low profile dynamic force sensors which can be arranged in an array to yield a model of the pressure distribution on the surface of the buttocks. The second is the development of noninvasive techniques for measuring the distribution and geometry of tissue and to model tissue behavior under various loads (e.g. finite element analysis). The combination of a sensor array and a model of tissue behavior could lead to an understanding of how cushions need to be designed to prevent pressure sores.

Recently, conductive polymer sensors have become commercially available which with some modification may be suitable for measuring cushion interface pressure (Webster, 1989). This paper will focus on the characterization of a conductive polymer resistive force sensor (Interlink) and some adaptations which may make it suitable for measuring cushion interface pressure.

## Statement of the Problem

Conductive polymer resistive force sensors are inexpensive, light-weight, and small. However, they are sensitive to how pressure is applied, and their response is nonlinear. In addition, they have been used in some applications without knowledge of how they operate. This may produce erroneous results.

## Rationale

The development of a reasonably priced normal force sensing mat or pressure sensing pants may yield the external loading data required for finite element or other models of the internal distribution of pressure within the buttocks. This could lead to improvements in cushions and reductions in pressure sores. However, the properties and limitations of these sensors needs to be understood before they are applied. The efficacy of the data is dependent upon the quality of the sensor.

## Design

A commercially available conductive polymer resistive force sensor (Interlink) was analyzed, characterized and then modified for use in measuring cushion interface normal force.

Analysis: The base conductive polymer resistive force sensor consists of three main parts: 1) a round piece of mylar coated with a circle of a conductive polymer ink, 2) a thin metallic ring with an inside diameter slightly larger than the diameter of the conductive polymer, and 3) another round piece of mylar with traces printed onto it in a pattern of interlocking fingers (**Figure 1**). The leads come from the piece of mylar with the fingers printed on it. Without any force upon the sensor, the resistance is nearly infinite (the fingers do not touch and the air gap prevents conduction through the polymer ink). As pressure is applied the conductive polymer ink begins to touch the traces of the opposite mylar film and the resistance between the leads drops (the resistance of the polymer ink remains constant). As more pressure is applied the contact area increases and the resistance drops further. However, the contact area depends upon where the pressure is applied, there is greater contact with more fingers in some areas than there is in other. The range is typically between 12M ohms and 100 ohms. This range is large enough to be measured by very simple circuitry.

Characterization: The resistances of five (1.5 inch square, .75 inch square, .25 inch square, .5 inch circle, .375 inch circle) Interlink pressure transducers were measured over a range of 0 to 50 pounds. Force was applied uniformly across the entire sensing surface using an electronically controlled press and it was measured using a force gage (AMETEK AccuForce II). The force on each transducer produced a resistance which was measured using a digital multimeter (Tektronix CDM250). At least three trials were run for each transducer. Each trial started a zero and force was slowly increased to 50 pounds. A resistance reading was recorded for every pound. The ensemble mean for each transducer is plotted in **Figure 2**.

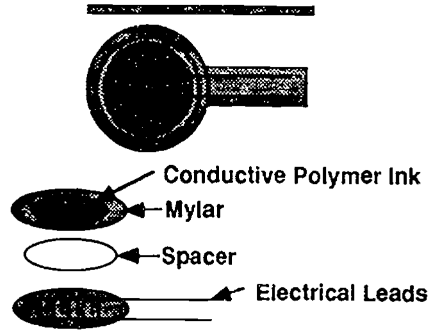


**Figure 1. Basic Conductive Polymer Force Sensor**

## Development

Based upon the results of testing, 1/2 inch circular transducers were chosen for modification. Two .0625 inch thick fiberglass disks (thinner carbon fiber disks are being developed) were placed on either side of the transducer (**Figure 3**). The disk on the polymer side was .375 inches in diameter whereas the disk on the lead side was .5 inches in diameter. The disks were adhered to the sensors with inert silicone sealer. The conductor side layer of silicone sealer was applied thinly and then held with a 5 pound force to cure for 24 hours (this help to ensure a thin layer of uniform thickness). The conductive polymer side silicone layer was applied more generously. The disk for this side was placed on the silicone adhesive and the transducer was placed in a jig which to set the thickness of the silicone layer to .04 inches (1 mm) and was allowed to cure for 24 hours. The modified transducer was then tested similarly to the basic transducers.

## Evaluation

The results of testing the basic and modified 1/2 inch circular transducer are shown in

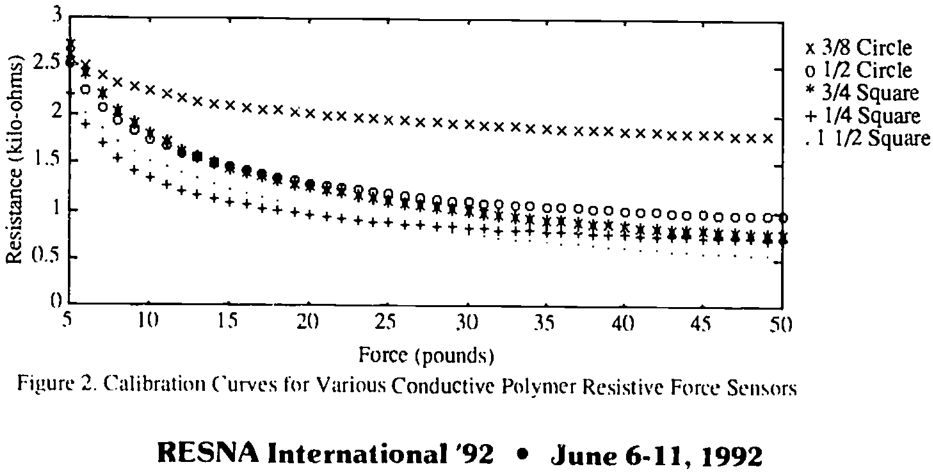


Figure 2. Calibration Curves for Various Conductive Polymer Resistive Force Sensors

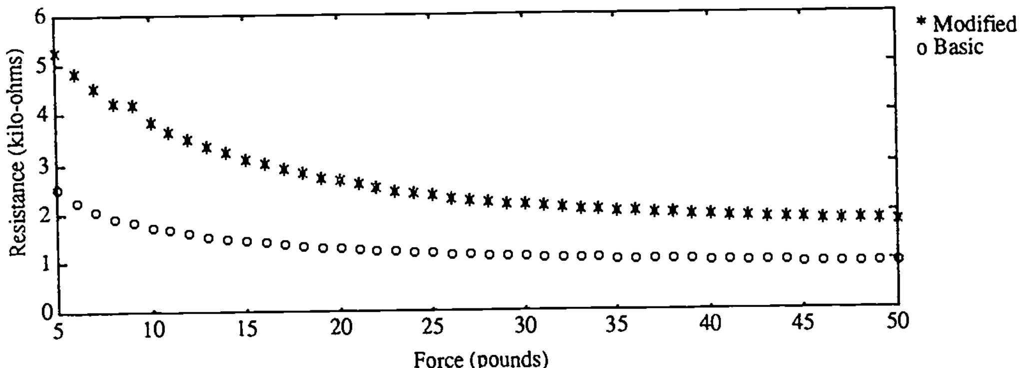


Figure 4. Calibration Curves for Basic and Modified 1/2" Circle Conductive Polymer Resistive Force Sensors

**Figure 4**. The modifications to the transducer improved the repeatability of the measurements and made it less sensitive to the location of the force on the transducer. This is because the disk and silicone layer help to distribute point loads over the entire sensing surface. The additional thickness from the polymer side disk and silicone help to alleviate the problems of erroneous readings due to the air gap ring. The air gap ring reduces the force seen by the sensor when in contact with soft tissue or very stiff tissue whose area extends over the ring. The sensor retained its log log relationship after modification (r = .894).

## Discussion

Simple modifications to conductive polymer resistive force transducers may make them suitable for measuring seating interface normal force. The repeatability and reliability can be improved. The nonlinear characteristics of the sensor can be overcome by using logarithmic regression or a look-up table. Materials suitable for thinner disks need to be investigated further. The modified transducers need to be integrated into a flexible array (e.g. lycra pants) and tested further. However, this line of research appears to show promise for assisting with cushion design and evaluation.

## Acknowledgements

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Rory A. Cooper
Coordinator
Rehabilitation Engineering Program
Biomedical Engineering Department
California State University
Sacramento, California 95819-6019

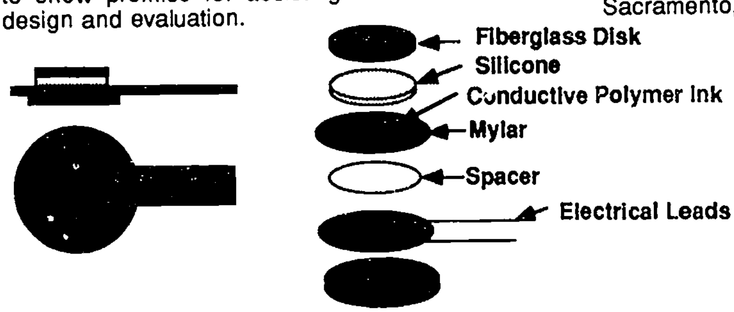


**Figure 3. Modified Conductive Polymer Resistive Force Sensor**

# Pressure Distribution on Custom Contoured Wheelchair Cushions Utilizing the Electronic Shape Sensor

Anita Perr, OTR/L, Andrew Lincoln, MS, Thomas McGovern, MS
REquest Rehabilitation Engineering Center
National Rehabilitation Hospital
Washington, DC USA

## Abstract

A pressure distribution study of custom contoured wheelchair cushions was performed as part of an ongoing clinical Beta site evaluation of the University of Virginia (UVA)-REC CAD/CAM Seating Assessment System. The purpose of the evaluation was to examine the overall feasibility of the system and the effectiveness of the Custom Contoured Cushion (CCC). During the evaluation, many clinical factors were recorded and analyzed. This paper reports on only one aspect of cushion effectiveness: pressure management. Interface pressures of the seat were measured at five anatomical locations on subjects' original cushions and the CCC that was provided by the seating system. Results suggest that there was a redistribution of pressure on the CCC.

## Introduction

High pressures on seating surfaces over time can decrease local blood flow and cause tissue necrosis resulting in pressure sores.[1] Theoretically, contoured cushions effectively distribute the load in a more even pattern to eliminate peak pressure areas.[2] In addition, contoured seat cushions may offer enhanced postural support. The UVA-REC has developed a computer assisted technique to design and fabricate custom contoured cushions, the CAD/CAM Seating Assessment System, that is being prepared for market. It appears to fill a void in the rehabilitation of persons with spinal cord injuries and other disabilities who use wheelchairs by providing a better wheelchair cushion at reduced cost and delivery time. Essentially, foam blocks are carved to exactly match the seated contour of the wheelchair user, taking into account the tissue displacement that occurs in the seated position.

## Objective

This segment of the evaluation considered the effects of custom contoured cushions on pressure distribution by an individual using a wheelchair. The two main objectives of this study were: 1) to utilize a standardized methodology provided to five clinical centers to measure baseline interface pressures for subjects with various diagnoses and seating systems; and 2) to obtain additional measurements with the custom contoured cushion to determine the effectiveness of pressure management with the CCC.

## Methods

Each of five Beta sites[3] collected data regarding demographics, posture, function, and pressure on subjects meeting previously defined criteria. Criteria for subject participation included no history of skin breakdown on the sitting surface for six months preceding participation; wheelchair used as their primary means of mobility; and sufficient sitting tolerance to participate in the evaluation.

During the initial evaluation, the clinicians collected demographic data, evaluated posture, function and pressure and collected contour data to design a CCC. A detailed description of the computer-assisted method to collect contour data and fabricate a cushion is published elsewhere and therefore is not included here.[4] Pressure measurements were taken using the subjects' original cushions. Pin-Dot Products (Niles, Illinois) fabricated all CCCs using the numerical data obtained by the Electronic Shape Sensors at the Beta sites. The variety and distribution of wheelchair cushions used by the subjects are listed in Table 1.

Table 1. Cushion Type (n=57)

| Type | Number |
|---|---|
| Jay | 20 |
| Quickie | 12 |
| ROHO- High Profile | 7 |
| ROHO- Low Profile | 6 |
| Other | 11 |

Pressure on the sitting surface was measured using the SCIMedics-Talley (Hampshire, England) pressure monitor. Evaluators primarily used a 4" bladder. The bladder was placed between the subject and the sitting surface at seven sites: the left and right ischial tuberosities (IT) placing the bladder directly under the tuberosity; the left and right trochanters placing the bladder at the greater trochanter of the femur; under the left and right thighs placing the edge of the bladder at the front edge of the subject's wheelchair cushion; and at the coccyx/sacrum placing the bladder directly under the coccyx and/or sacrum. Pressure measurements were taken in the following sequence: right ischial tuberosity, left ischial tuberosity, right trochanter, left trochanter, right thigh, left thigh, and coccyx/sacrum. The sequence of pressure measurements was repeated to obtain three independent measures. The average of the measurements at each site was calculated and used for subsequent analyses. Because the SCIMedics-Talley pressure monitor is difficult to accurately read at the lower end of the scale, any pressure readings below 20 millimeters of mercury were recorded as 20 mmHg.

Results

Fifty-seven subjects presenting a variety of diagnoses participated in the study. Demographic information can be found in Table 2. Each subject was to participate in two sessions with the Beta evaluators. At the time this report was written, each of the 27 subjects who returned for their second session received a contoured cushion.

Table 2. Subject Demographics (n = 57)

| | |
|---|---|
| Sex | M: 43 F: 14 |
| Mean Age (years) | 40 |
| Mean Weight (lbs.) | 155 |
| Mean Height (in.) | 68 |

| Diagnosis | Number |
|---|---|
| SCI-Quad | 21 |
| SCI-Para | 18 |
| Post Polio | 5 |
| MD | 4 |
| MS | 3 |
| CP | 2 |
| Other | 4 |

No attempt was made to compare pressure measurements between the various cushions. Rather, the data were analyzed grouping all of the subjects together. Pressure measurements for two of the 57 subjects were lost to the evaluation.

Mean pressures on the subjects' original cushions can be found in Table 3. The highest localized pressures were found at the ischial tuberosities. Pressures at the trochanters were less than at the ischial tuberosities and pressures were lowest at the thighs. Pressure at the sacrum was similar to that at the trochanters. These results closely match findings of previous investigators.[2]

Table 3. Mean Pressure (SD) on Original Cushions (n = 55)

| Site | Pressure (mmHg) | |
|---|---|---|
| | Left | Right |
| IT | 62 (28) | 63 (29) |
| Trochanter | 41 (15) | 41 (15) |
| Thigh | 24 ( 6) | 22 ( 4) |
| Sacrum | 39 (20) | |

Mean pressures on the custom contoured cushions are listed in Table 4. Overall, the distribution of pressure over the contoured cushions was similar to that on the original cushions with the highest pressures at the ischial tuberosities, less at the trochanters and sacrum and the least pressure at the thighs.

Table 4. Mean (SD) Pressure on Custom Contoured Cushion (n = 27)

| Site | Pressure (mmHg) | |
|---|---|---|
| | Left | Right |
| IT | 57 (21) | 50 (13) |
| Trochanter | 41 (12) | 37 (13) |
| Thigh | 26 ( 9) | 26 ( 7) |
| Sacrum | 36 (20) | |

The results of paired t-test analysis of the pressure differences with different cushion use are shown in Table 5. The results indicate that although a similar decrease was observed at both ischial tuberosities, only the decrease on the right side was statistically significant ($p < 0.05$). Similarly, only on the right side was the thigh pressure significantly increased.

Table 5. Paired t-test for Mean (SD) Pressure Measurements (n = 27)

| Site | Pressure (mm Hg) | | Signif. |
|---|---|---|---|
| | Original | CCC | Level (p) |
| Right IT | 64 (29) | 50 (13) | 0.024 |
| Left IT | 71 (32) | 57 (21) | 0.064 |
| Right Troch. | 38 (14) | 37 (13) | 0.609 |
| Left Troch. | 40 (14) | 41 (12) | 0.535 |
| Right Thigh | 21 ( 6) | 26 ( 7) | 0.012 |
| Left Thigh | 22 ( 7) | 26 ( 9) | 0.062 |
| Sacrum | 42 (21) | 36 (20) | 0.344 |

These data indicate a small decrease in pressure at the ischial tuberositites and a small increase in pressure at the thighs, thus indicating a possible shift in weightbearing from the bony areas of the ischial tuberosities to the thighs which might be more suitable for weightbearing. However, a dramatic redistribution of pressure was not observed.

Discussion

Comfort, function and pressure distribution all play important roles in choosing the correct wheelchair cushion. Custom contouring a foam wheelchair cushion may play a role in altering the pressure distribution over the sitting surface. This study indicates a change in pressure at the ischial tuberosities and the thighs with the use of a custom contoured cushion. However, the change in the distribution of pressure from the subjects' original cushion to the CCC was relatively small. Even small decreases in pressure may, however, influence the ability of a patient to bear weight and reduce the likelihood of pressure sore formation or increase the patient's sitting tolerance.

The smaller standard deviations in pressure measurement for custom contoured cushion users observed at the ischial tuberosities suggest a more consistent interface pressure. This may suggest a reduction in tissue distortion when provided with a custom contour. Additional data from the outstanding 30 subjects should provide a more complete analysis.

Evaluators were instructed to record any pressures less than 20 mmHg as 20 mmHg. This may have resulted in skewed results especially for the pressure under the thighs. It was observed that some subjects bore little or no weight under their thighs on their original cushions. The pressures which were recorded as 20 mmHg may actually have been lower. This suggests that the pressure under the thighs was actually increased by more than what was reported in these results with a custom contoured cushion.

Conclusion

Custom contoured cushions fabricated using the CAD/CAM Seating Assessment System developed by the UVA-REC may decrease pressure at the ischial tuberosities and increase pressure at the thighs. While the patterns of pressure distribution remain essentially the same (highest at the IT's, lower at the trochanters and sacrum and still lower at the thighs), the pressure was shifted somewhat from an area prone to skin breakdown, the ischial tuberosities, to an area better suited for weightbearing, the shafts of the femurs. It is expected that with a larger subject pool, patterns of change will continue to show this shift in pressure with the values on the left and right sides balancing.

Acknowledgements

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Contact:
Anita Perr, OTR/L
REquest Rehabilitation Engineering Center
National Rehabilitation Hospital
102 Irving Street, N.W.
Washington, DC 20010

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# THE DESIGN OF A COMPUTER AIDED SEATING SYSTEM

Rick Kwiatkowski, Rafael Inigo
University of Virginia Rehabilitation Engineering Center
Charlottesville, Virginia USA

## ABSTRACT

A novel system designed for the measurement of the loading of the human body on a seating surface is reported. The system measures seating surface forces and can control the seating contour. Using force information as feedback, the system is capable of determining custom seating contours which produce optimum seating characteristics. The system is comprised of an electronically actuated and force-sensing seating surface which is controlled by a computer. Figure 1 illustrates the major components of the seating system.

## BACKGROUND

It has been determined that custom contoured cushions can help reduce seating-related illnesses which afflict wheelchair users. For this reason, systems have been designed to aid in the measurement and fabrication of such contoured cushions. Some existing systems operate by measuring the displacement of an array of probes which constitute the seating surface. The individual probes are spring-loaded and resist vertical displacement [1]. The measured displacement due to the loading of a human body is then used to specify the cushion contour which will be fabricated. These systems can be described as "open-loop" since the "desired" seating characteristics are not incorporated into the displacement measurement. Some of these systems allow for a variety of spring stiffnessses which can be helpful for measuring individuals with various masses. However, the existing systems do not allow for simultaneous contour control and seating force measurement. A "closed-loop" system would allow for more direct control over a cushion's seating characteristics. Work on such a system was started by Brienza and Gordon at the UVA REC [2,3]. This paper reports progress in this effort.

## RESEARCH QUESTION

The purpose of this project is to determine a way that force-feedback can be implemented in a closed-loop seating system and meet the specifications listed below.
1) The system should be able to measure seated individuals with masses up to 100 kg.
2) The seating surface should be made up of an array of movable force sensing probes arranged in an 18" by 18" area.
3) Each probe should be capable of measuring static

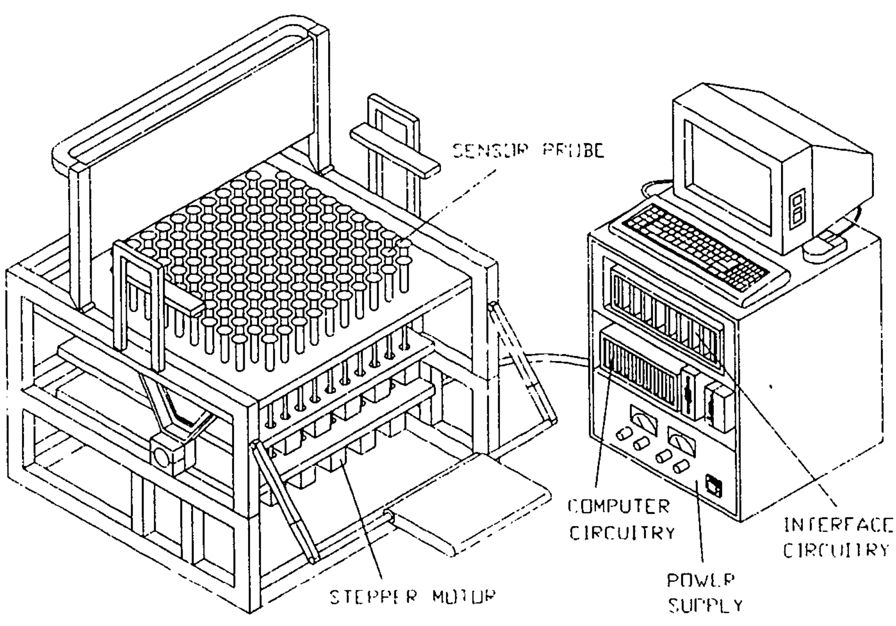


Figure 1 System Components

forces normal to the seated surface ranging from 20 to 5900 grams with a resolution of 25 grams.
4) The vertical position of each probe should be controllable under maximum load to the maximum displacement of 5 inches with a resolution of 0.01 inches.
5) The orientation (tilt and rotation) of each probe surface should be measurable. The tilt angle should be measured from 0 to 50 degrees with respect to horizontal with a 0.5 degree resolution. The rotation angle should be measured from 10 to 360 degrees about a designated reference. Up to 10 degrees of unmeasurable travel is allowed for due to the method of measurement.

These specifications were chosen to ensure that the system would be able to measure 95% of the potential subjects as well as ensuring the displacement and force resolutions to be as good as, or better than, existing systems.

## METHOD

Actuators: The seating surface consists of an 11 by 12 rectangular array (minus the four corners) of movable force sensing probes. This array configuration was used successfully on previous systems and was adopted for the new system. Where the earlier systems used springs to counteract the seating forces, the new system uses motor-driven actuators which can position each probe vertically within a 5 inch range. Since 128 motors are required (one for each probe), size of the motors is an important consideration. The stepper motors chosen are small enough to allow two layers of 64 motors to fit in the available 18" by 18" cross-sectional area and powerful enough to lift the rated 5900 gram load when coupled with acme drive screws. Also, the stepper motors allow the position of a given probe to be calculated from the number of pulses sent to the respective motor. This eliminates the need for separate position sensors for each probe.

Sensors: Each probe is designed to measure the force acting normal to the surface between the probe and seated individual. Figure 2 shows the cross section of a typical sensor probe. Each probe is attached to a stepper motor by a drive screw and nut (not shown in figure). The probe surface is rigid and transmits the forces down a connected shaft to a force transducer. The force transducer converts the measured forces to electrical signals which are processed by the computer. The force transducer is comprised of a piezo-resistive pressure sensor which converts forces from pressurized liquids to electrical signals. There are many available, inexpensive pressure sensors which can be purchased for this application. Silicone fluid is sealed in a cylindrical chamber with one end containing the pressure sensor and the other a flexible rubber diaphragm. A shaft attached to the probe surface makes contact with the diaphragm and transmits forces to the silicone fluid.

To allow for curved contours, each probe surface consists of a conical head which tilts and rotates freely with the seated surface by means of a ball and socket joint. The orientation of the probe head is detected by two separate potentiometers which measure its tilt and

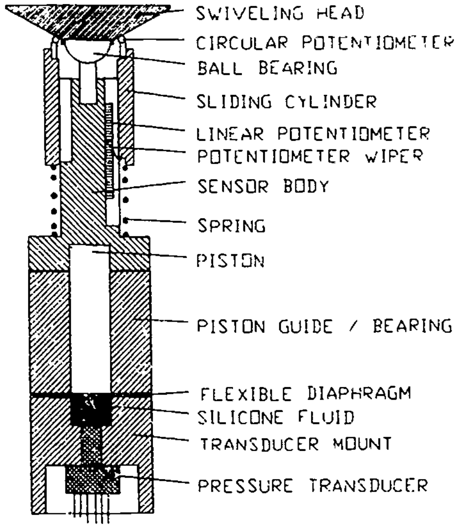


Figure 2 Typical Sensor Probe Cross Section

rotation. The potentiometers convert the associated head rotation angles to electrical signals which are processed by the computer. The probe head can rotate freely 360 degrees about the center axis of the connecting shaft. A rotary potentiometer attached to the top of a sliding cylindrical collar measures the contacting point of the conical probe head, thereby determining the head rotation. This potentiometer measures the full 360 degree rotation minus a contact angle of about 10 degrees. The sliding collar is spring loaded and resists the tilt of the head. A wiper attached to the collar makes contact with a linear potentiometer mounted on the probe body. As the probe head tilts, the collar is forced to slide down the probe body causing the wiper to travel along the linear potentiometer [2].

Computer and Interface: The probes are connected to a computer cabinet via cables and interfacing circuitry. The cabinet contains an STD bus multiple processor computer with its related I/O and user interfacing equipment. The system contains a monitor, keyboard and mouse for user interaction. The cabinet contains a D.C. power supply which is used for energizing the stepper motors, the force transducers and the orientation potentiometers as well as the supporting circuitry. Attached to the chair unit, analog multiplexers are used to scan the force and orientation signals before they are digitized and sent to the computer. Also located on the chair unit are controller cards which receive digital signals from the computer and convert them into the drive pulses for the stepper motors [2].

## RESULTS

At the time of this writing, the design portion of the project has been completed. All of the system components have been identified and the majority of the parts have been purchased. Three fourths of the construction of the system has been completed. All of the computer and related I/O circuitry has been installed and tested. All of the stepper motors and related actuators have been installed. The orientation potentiometers have been tested. The individual probe components are currently being built. Prototype probes have been fully built and tested and have met the required specifications. Software has been written and tested for controlling a smaller group of probes and will be extended for the full system.

## DISCUSSION

The system is expected to be a research tool which can provide information about how seating contours affect the forces which react normal to the seating surface. Additionally, the system as described is capable of determining stiffness characteristics of the seated surface. Stiffness can be measured at a probe site by displacing the probe a short distance and recording the change in the surface force [2]. Stiffness considerations can be incorporated into the cushion contour design to create desired loading effects. For example, it may be desirable to reduce pressures at high stiffness, thin skin areas and to distribute these pressures to lower stiffness, thick-skin areas. This system is unique since it can control the contour of the seating surface and simultaneously measure the loading effects at the seating interface. In this way, the system can incorporate characteristics like stiffness into algorithms which compute optimal cushion contours.

Much care has been taken to design a tool that measures forces which are accurate and repeatable. As was pointed out by Guthrie [4], it is extremely difficult to measure pressures between two compliant surfaces since the curvatures of each surface must be known. To avoid this situation, the probe heads are flat and rigid so the shape of the measured interface is known. Each probe is calibrated and is accurate throughout the designed load range for flat and curved contours.

An additional use for the seating system is the measurement of cushion properties. A compliant material can be placed on the flat or contoured actuator array and force information can be measured under various loadings of the material. Information about how materials transmit forces to base supports can be determined from this applicatior [-].

It is hoped that the use of this system will make contributions to the area of seating technology and will ultimately lead to improvements in the quality of life of many people with disabilities.

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UVA Rehabilitation Engineering Center
Box 3368 University Station
Charlottesville, VA 22903

# PRESSURE MAPPING SYSTEMS FOR SEATING AND POSITIONING APPLICATIONS: TECHNICAL AND CLINICAL PERFORMANCE

Martin W. Ferguson-Pell, Ph.D. and Mary Cardi, M.S., P.T.
Helen Hayes Hospital, Center for Rehabilitation Technology


## ABSTRACT

A prototype, computer based pressure mapping system was developed using existing technology that had been developed for other medical applications. The design was based on specifications from 10 clinical and research centers. The prototype and 3 commercial pressure measurement systems were compared for technical and clinical performance. For each system, clinician feedback, data and trends are presented for the relative influence of hammocking, hysteresis and creep. The findings of the study emphasize not only that three out of the four systems exhibit clinically significant inaccuracies of measurement due to these unwanted properties but also exhibit marked difference in values obtained under comparable loading conditions.


## INTRODUCTION

Over the last 10 years, two major clinical applications of pressure mapping systems have emerged. Pressure measurement has been used by many centers for selection of support devices for individuals at risk for developing pressure sores (1)(2)(3). Use of pressure mapping is increasing in the evaluation of positioning or postural support and seating systems (4). Such objective documentation assists decision-making for prescription and communicates findings succinctly to colleagues including justifications to third party payors.

A number of studies have identified sensor characteristics which influence interface pressure measurements and must be considered when interpreting readings (5)(6). The few mapping systems that have been available commercially have been limited in performance in the following areas:

- poor durability
- potential inaccuracies on compliant cushions due to "hammocking"
- inadequate spatial resolution
- large sensor elements which cause peak pressure "averaging"
- sensor arrays too small for full seat mapping

Most computer-based systems have been limited in data presentation and manipulation for measuring and recording dynamic changes associated with functional activities.

The purpose of this project was to develop an improved pressure mapping system and compare its measurement and performance with three commercial systems. A focus group of 3 clinical specialists was formed to compare the systems for use in patient assessments.

## METHODS AND MATERIALS

**Pressure monitoring devices tested:**

The prototype system was developed by Tekscan Inc. (Cambridge MA) in collaboration with the authors who provided detailed performance and user interface specifications based on responses to a questionnaire by 10 experienced seating specialists and researchers. The prototype contains 2056 sensing elements, their center's 10mm apart on a mapping area of 430 x 490 mm. Each sensor is approximately 8mm x 8mm. The system employs a force sensitive ink which is applied to the mat's thin, flexible polyester substrate 0.1 mm thick, using an advanced lithographic technique. The system features very high spatial resolution, high sampling rate and a graphical interface that provides high quality, two and three dimensional representations of the pressure distribution at the body-support interface. It also allows short duration dynamic pressure distributions to be recorded and played back at normal speed or frame by frame.

The Tekscan prototype was compared with three commercial systems: Force Sensing Array (FSA) from VISTAMED (Winnipeg, Canada); Talley TPM3 and Talley Pressure Evaluator (Talley Medical Equipment Romsey, England).

The FSA system uses 225 sensors manufactured by Interlink Electronics (Santa Barbara CA) whose active element is an electrically conductive ink. They are arrayed in a 510mm x 510mm mat. Pressures can be monitored either instantaneously or at a sampling rate of approximately 1 complete array of sensors per second. Data is presented either as color encoded isobars, proportional squares, as numerical values or as a 3D contour map.

The TPM3 monitors a pneumatic pressure vs air flow rate characteristic associated with each small air bladder used as a sensor. The TPM3 can be used as a stand- alone system where values are presented on a LCD display, or in conjunction with a personal computer. The TPM3 can accommodate up to 96 discrete sensors and is also supplied in 8x12 sensor arrays and a 510mm x 510mm, 48 sensor mat (TALMAP) to place on wheelchair cushions.

The Talley Skin Pressure Evaluator (TSPE) is a small hand-held portable unit employing a sphygmomanometer connected to a bladder with electrical contacts to indicate whether the bladder is inflated or has been collapsed by the applied interface pressure. The TSPE can be supplied with 100mm and 28mm diameter sensor bladders.

Calibration Techniques:

A planar loading calibration method was used to calibrate each system. Transducers were sandwiched between an inflatable vinyl bag above, and a 15mm thick elastomeric gel ("T-Gel", Alimed Inc. Boston MA) which were contained in a strong wooden box with an access slot to insert the transducer at the front. The inflation pressure of the vinyl bag was equated to the pressure applied to the transducer.

**Linearity** was determined by loading the mapping systems in the planar calibration rig and applying increments of 20 mm Hg up to 160 mm Hg. Linearity was expressed as the regression coefficient for the output versus applied pressure characteristic.

**Hysteresis** effects were examined by progressive interval loading and unloading of each system, except the TALMAP, results for this system were assumed to be the same as the TPM3 sensors in isolation. Increments of 20 mm Hg were applied and measurements recorded in the range 0-160-0 mm Hg.

**Stability** was determined for each of the systems applying pressure at two levels (50 and 100 mm Hg) successively. In each case the output of the sensors was measured immediately upon reaching the prescribed pressure, at 30s and then at 60s intervals up to 600s.

**Repeatability** was determined using a loader gauge fabricated to nominally simulate buttock loading. A loader gauge is preferred to employing human subjects as small variations in body position are difficult to control and can result in large variations in local interface pressure. The variation in peak pressure for 10 repeated loadings was compared for each of 4 test cushions (Foam, gel, Roho, Jay).

**Hammocking** effects were estimated by instrumenting the loader gauge with three 12mm diameter Interlink sensors. Instrumentation was developed to average the output of the 3 sensors and express their response to applied pressure in mm Hg. The sensors were placed on the ischial tuberosity region of the loader gauge, which was then placed on each of the test cushions. The average output of the sensors was then recorded. This procedure was then repeated with each of the pressure mapping systems interposed between the cushion and the instrumented loader gauge. Comparison between the average Interlink sensors' output with and without the transducer provides an indication of how much modification of the "natural" pressure distribution occurs due to the presence of the transducer.

Patient Tests:

Measurements were made to determine the reproducibility of the mapping systems with experienced wheelchair users at risk for developing pressure sores. Each of 5 subjects exhibited prominent ischial tuberosities. Pressure measurements were taken with each subject seated in his own wheelchair with a solid seat board. For each cushion, single readings were taken for each of the pressure mapping systems, on each of the 4 cushions.

## RESULTS

**Clinical Focus Group**

Overall, the focus group participants found the TPM3 to be the most limited in speed, ease of use, clinical efficiency and ready interpretation of data presentation. The FSA was found to provide clinically useful, easily interpreted data and clear, comprehensive data files including hard copy. The Tekscan's spatial resolution, data presentation and ease of operation were rated to be superior to the other systems and the dynamic recording capability was found to be useful in simulating the effects of functional activity. Lack of software for numerical display, printing and data retrieval were identified as weaknesses.

Table 1: Linearity and calibration reproducibility

| | Mean Measured Pressure | | | |
|---|---|---|---|---|
| APPLIED PRESSURE (mm Hg) | TPM3S [10] | FSA [5] | TEKSCAN COVERED [5] | TEKSCAN UNCOVERED [1] |
| 0 | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (-) |
| 20 | 21 (0.6) | 14 (2.3) | 19 (1.7) | 15 (-) |
| 40 | 41 (0.3) | 40 (2.7) | 40 (1.5) | 34 (-) |
| 60 | 61 (0.3) | 60 (3.4) | 61 (1.6) | 51 (-) |
| 80 | 81 (0.0) | 81 (5.1) | 82 (2.0) | 68 (-) |
| 100 | 101 (0.0) | 103 (3.7) | 104 (1.6) | 87 (-) |
| 120 | 121 (0.0) | 129 (1.3) | 126 (2.8) | 103 (-) |
| 140 | 140 (0.5) | 147 (0.5) | 147 (1.6) | 122 (-) |
| 160 | 160 (0.5) | - - | 169 (1.5) | - - |
| Linearity ($r^2$) | 0.999 | 1.081 | 1.060 | 0.875 |

Table 2: Hysteresis

| MAPPING SYSTEM | HYSTERESIS |
|---|---|
| TEKNCOV | 21.7 |
| TEKCOV | 20.8 |
| TPM3S | 0.0 |
| FSA | 18.7 |

Table 5: Repeatability-loader gauge

| | PEAK PRESSURE mm Hg | | | | |
|---|---|---|---|---|---|
| CUSHION | FSA | TALMAP | TEKCOV | TEKNCOV | TPM3S |
| FOAM | 54(2) | 83(5) | 81(5) | 62(6) | 69(2) |
| GEL | 71(4) | 89(10) | 97(11) | 91(10) | 103(8) |
| JAY | 41(5) | 64(6) | 85(10) | 51(6) | 72(10) |
| ROHO | 33(5) | 45(4) | 57(3) | 42(9) | 48(8) |

Table 6:Example of mapping system measurement variation for 5 subjectsfor 1 support surface

| CUSH. | SUB | PRESSURE MAPPING SYSTEM | | | MAPPING | |
|---|---|---|---|---|---|---|
| | | FSA | TALMAP | TSPE | TEKCOV | TPM3S |
| FOAM | 1 | 91 | 107 | 81 | 173 | 122 |
| | 2 | 134 | 164 | 155 | 184 | 202 |
| | 3 | 84 | 85 | 75 | 103 | 84 |
| | 4 | 136 | 190 | 129 | 187 | 246 |
| | 5 | 106 | 94 | 72 | 82 | 88 |

DISCUSSION

Technical evaluation of the systems demonstrated that the Talley TPM3 is the most accurate, reproducible and stable, but was found to be clinically limited in scan rate, ease of use and data presentation. The two systems employing force sensitive inks showed significant hysteresis, although both plan to employ software algorithms to reduce this problem. The FSA was superior in terms of lower creep and calibration consistency. The data management and presentation features of the FSA were rated highly by the focus group. The Tekscan prototype exhibited the greatest creep and was found to lose calibration when subjected to shearing loads. Both FSA and Tekscan exhibited significant hammocking effects, the extent of which depended strongly upon the type of cushion being used. The focus group rated the Tekscan system highly for improved spatial resolution, data presentation, dynamic display and recording capabilities. Perhaps the most dramatic and disconcerting results were those obtained with high pressure sore risk wheelchair users. Each subject was asked to sit on 1 of 4 cushions in turn, with each of the pressure mapping systems being employed to determine the peak pressure. The variation in peak pressure recorded under virtually identical conditions on, for example the foam cushion, for a given subject, ranged from 81 mm Hg using the TSPE to 173 mm Hg for the Tekscan system. It is possible that some of the extreme differences could be accommodated using averaging techniques ("smoothing"), but the variations between systems would still remain high.

These observations reinforce concerns that the interpretation of pressure measurements using these systems should at best be limited to relative comparison between similar support surfaces. They should not be used as absolute measures for risk assessment ischemia tolerance.

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Further information:
Martin Ferguson-Pell, Ph.D.
Helen Hayes Hospital
Center for Rehabilitation Technology
Route 9W, West Haverstraw, NY 10993

# Three-Dimensional Computer Model of the Human Buttocks, *In Vivo*

Beth A. Todd[1] and John G. Thacker[2]
[1]GMI Engineering & Management Institute, Flint, MI
[2]University of Virginia-Rehabilitation Engineering Center, Charlottesville, VA

ABSTRACT

Three-dimensional, PC-based, finite element models of the human buttocks were generated for able-bodied male and female subjects in both seated and supine positions. A force propo' onal to each subject's weight was applied as a point-load to each model. Elastic foundation boundary co-ditions were applied to the soft tissue. Displacements of the soft tissue under the right ischial tuberosity and buttock-cushion interface stresses calculated from the model were acceptable when compared with their experimentally determined counterparts. Internal stresses closer to the ischial tuberosity, which could not be measured experimentally, were calculated to be larger than those at the buttock-cushion interface.

BACKGROUND

Development of decubitus ulcers is a serious problem for those who are wheelchair bound, particularly paraplegics and quadriplegics. While the first indication of an ulcer is redness on the skin surface, there is surgical evidence that ulcers form internally and spread toward the surface of the skin. Developers of wheelchair cushions make use of interface pressures between the buttocks and the cushion when designing to relieve pressure. There is limited information available relating interface pressures to the internal pressures at the sites of decubiti formation.

The purpose of this research was 1) to show that a finite element model could be developed which gave results consistent with experimental data and 2) to begin to relate interface pressures to internal pressures.

METHOD

Modeling the human body can be quite complex. To minimize the complexity of the model, only a portion of the right buttock around the ischial tuberosity was included in the model. Two subjects were used in this study: an able-bodied male of mass 74 kg and an able-bodied female of mass 58 kg. Models were created for each subject to represent seated and supine positions on a contoured cushion. To develop a finite element model, geometry of the structure must be defined, material properties determined, and loading and boundary conditions established.

Geometry
With the exception of the cushion itself, the geometry in this case consisted of the anatomical dimensions of the right ischial tuberosity and surrounding soft tissues. Nuclear Magnetic Resonance Imaging (MRI) was used to determine these dimensions.(1) A planar section of the three-dimensional model of the male subject is shown in Figure 1. Due to the size of the tube in the MRI imager, subjects could not be placed in a seated position. Material properties were used to compensate for the fact that supine geometry was used in both seated and supine positions.

Material Properties
The modulus of elasticity and Poisson's ratio of bone were taken from the literature. An experiment was developed to determine the material properties of the soft tissue for each subject in each position. Details of this experiment are described in the references.(2) Material properties of the cushion were determined using load-deflection tests.(2),(3) The values of the material properties used in the models are given in Table 1.

Loading
The loading applied to each model was taken as a percentage of the subject's total body weight. For an average male in the supine position, the right pelvis represents 6.7% of the total body weight; in the seated position, the loading on the right ischial tuberosity is 29.2% of the total body weight. For an average female in the supine position, the right pelvis represents 8.6% of the total body weight; in the seated position, the loading on the right ischial tuberosity is 29.7% of the total body weight.(3) In each case, the weight was applied to the model as a point load acting on the ischial tuberosity. The forces used for loading are given in Table 2.

Boundary Conditions
The model was constrained at several locations. A symmetry condition, eliminating horizontal motion, was placed on the right edge of the model to represent bilateral symmetry. The bottom edge of the cushion was constrained against vertical motion. The front and back faces of the model were constrained to reduce complexity. The top surfaces of the soft tissue were constrained by elastic foundations. It is beyond the scope of this paper to go into the mathematical details of an elastic foundation. The interested reader is referred to the literature for more detail.(2) Material properties of the elastic foundations are listed in Table 1. The model was generated with a PC-based finite element program called PRIMEGEN™. The model of the male subject consisted of 2029 nodes and 1008 eight-node linear brick elements. The model of the female subject consisted of 2053 nodes and 1008 eight-node linear brick elements.

RESULTS

Model Verification
The finite element models were verified by comparing the displacements calculated in the supine position with those determined experimentally with the MRI. Also, the stresses calculated at the boundary of the soft tissue

and the cushion were compared with the interface pressures measured with the Oxford Pressure Monitor. The displacement values are listed in Table 3. The stresses are given in Table 4.

Interface and Internal Stresses
Stress contour plots show the change in stress through the soft tissue from the buttock-cushion interface to the ischial tuberosity. An example of these plots for the male subject in the supine position is shown in Figures 2 and 3 for two different stress ranges. The stress values for the different loading cases are given in Table 5.

DISCUSSION

Model Verification
The computationally and experimentally determined values for deflection of tissue under the ischial tuberosity are in excellent agreement for the male subject, but there is a 100% error for the female subject. Unfortunately, the MRI does not provide any way to mark the anterior-posterior position of a slice. There may be some discrepancy between the slice that was used to determine experimental deflection and the model cross-section used to determine the computational deflection.

The difference between computed stress and measured pressure was 1000 Pa and 1300 Pa for the male and female subjects, respectively, which gives between a 21 and 38 % error. While this error appears to be large, 1000 Pa is equivalent to 7.5 mm Hg. Readings on the Oxford Pressure Monitor are only accurate to within 4 mm Hg.

Interface and Internal Stresses
Table 5 shows a dramatic difference of greater than an order of magnitude between the minimum principal stresses at the buttock-cushion interface and the soft tissue surrounding the ischial tuberosity. The high stresses surrounding the tuberosity may be an artifact of loading the model with a concentrated point force. However, this increase in stress at the internal tissues bears further investigation.

ACKNOWLEDGEMENTS

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Beth A. Todd
Mechanical Engineering Department
GMI Engineering & Management Institute
1700 West Third Ave.
Flint, MI 48504

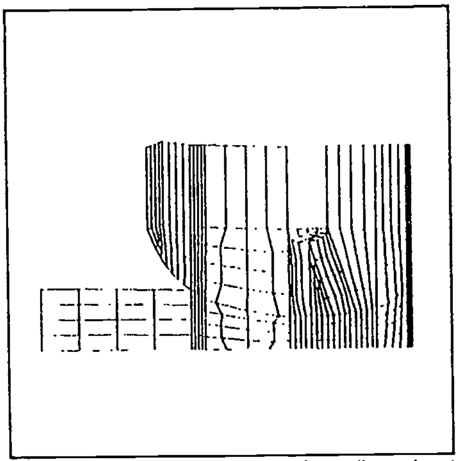

Figure 1. Planar section of the three-dimensional model of the male subject.

Table 1. Material Properties used in Models

| Material | E (Pa) | ν |
|---|---|---|
| Bone | $17. \times 10^9$ | 0.31 |
| Cushion | $10.2 \times 10^3$ | 0.1 |
| Female Elastic Foundation | $110 \times 10^3$ | 0.49 |
| Male Elastic Foundation | $120 \times 10^3$ | 0.49 |
| Male Seated Soft Tissue | $64.8 \times 10^3$ | 0.49 |
| Male Supine Soft Tissue | $15.2 \times 10^3$ | 0.49 |
| Female Seated Soft Tissue | $47.5 \times 10^3$ | 0.49 |
| Female Supine Soft Tissue | $11.9 \times 10^3$ | 0.49 |

Table 2. Loads Applied to the Various Models (N)

| | Load |
|---|---|
| Male Supine | 48.4 |
| Male Seated | 211.0 |
| Female Supine | 48.5 |
| Female Seated | 167.5 |

Table 3. Displacement of Soft Tissue (cm)

| | PRIMEGEN™ | MRI |
|---|---|---|
| Male Supine | 1.7 | 1.7 |
| Male Seated | 5.0 | not available |
| Female Supine | 1.9 | 3.9 |
| Female Seated | 6.4 | not available |

Table 4. Skin-Cushion Interface Stresses (Pa)

| | $\lvert\sigma_3\rvert$ | $\sigma_{von\ Mises}$ | Oxford Pressure Monitor |
|---|---|---|---|
| Male Supine | 5100 | 4600 | 4100 |
| Male Seated | 25300 | 37200 | not available |
| Female Supine | 4100 | 3100 | 2800 |
| Female Seated | 19800 | 21400 | not available |

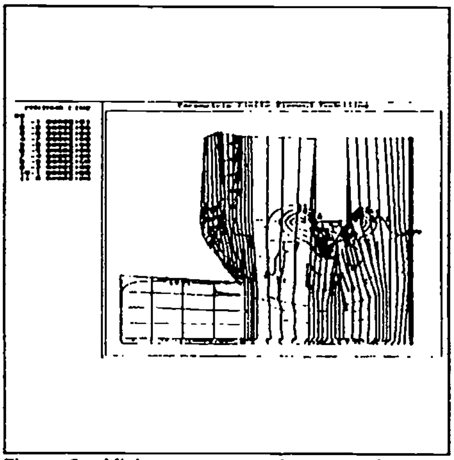

Figure 2. Minimum compressive stress for male subject in supine position, range 0 to -10. N/cm$^2$.

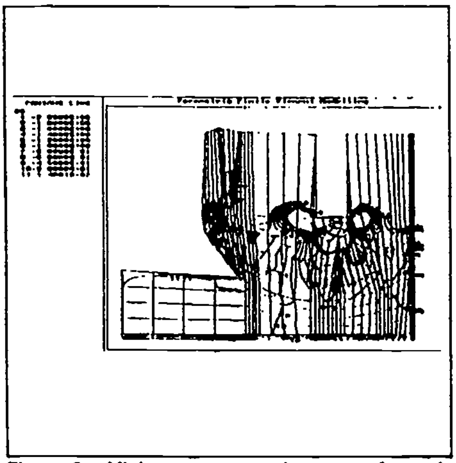

Figure 3. Minimum compressive stress for male subject in supine position, range 0 to -2. N/cm$^2$.

Table 5. Interface and Internal Stresses ($\sigma_3$ in Pa)

| | Interface | Ischial Tuberosity |
|---|---|---|
| Male Seated | -25300 | -150000 |
| Male Supine | -5100 | -100000 |
| Female Seated | -19800 | -480000 |
| Female Supine | -4100 | -130000 |

# FNS Knee Extension Exercise In Paraplegia: Factors Associated With Gains In Muscle Force Production And Work Performance

Joyce M. Campbell, Paul M. Meadows, Cynthia Wederich,
Robert L. Waters, Charles L. Carter
Rancho Rehabilitation Engineering Program, Downey, CA USA
California State University, Long Beach

## Abstract

FNS can improve joint stability and limb movement in SCI when muscle force production meets functional demands and is fatigue resistant (FR). The purpose of this poster is to present outcomes of FNS exercise designed to improve both knee extension moment (KEM) and FR in SCI. KEM and position (isokinetic system) were sampled by an IBM PC/AT. ES for laboratory trials was generated by the IBM. ES for home use was provided by a programmable, portable stimulator. Subjects performed a daily, home FNS program and a laboratory protocol 2x/wk for work goal-oriented FNS. Closed loop ES was programmed to maintain the target FNS moment, and exercise on each visit was completed when the KE work performance exceeded the previous session. Closed loop ES fatigue curves (maximum contraction over 40 KE, 60 deg/S) and work performance indicated both an increase in KEM and FR. A reduction in spasticity (documented as resistance to passive knee motion [5-230 deg/S]) contributed to improved KE. Combined volitional and FNS exercise produced greater peak KEM than did either mode of exercise alone.

## Introduction

Electrical stimulation can be used to augment joint stability and to create limb movement when force production is adequate and the quality of contraction is repeatable over time. Efforts to "strengthen" muscles weakened by spinal cord injury (SCI) with functional neuromuscular stimulation (FNS) have been confounded by altered motor unit recruitment, early fatigue and spasticity. Although previous investigators have demonstrated an improvement in electrically stimulated (ES) fatigue resistance as a result of FNS exercise, clinically significant increases in peak moment, or force generation, have not been consistently demonstrated (1-4).

ES activation of large muscle groups, such as the quadriceps, is critical to the success of FNS transfer and walking protocols for SCI patients. Based upon the muscle force generation requirements for standing and walking in healthy individuals, it is reasonable to expect that approximately 40% of normal knee extension force would be needed to support FNS activity.(5,6) In view of the lower force generation capability during joint motion, when compared to isometric muscle contractions, the estimated 40% should reference a shortening and/or lengthening muscle contraction.

The purpose of this report is to present the outcomes of an FNS knee extension exercise (KE) protocol in 8 SCI subjects and to emphasize the factors associated with improvement in force production and repeatability of muscle performance. 3 patients are highlighted to illustrate patient diversity in sensory, motor and reflexive status and response to FNS exercise.

## Methods

Subjects: Eight paraplegic patients participated in the FNS exercise protocol. All subjects lacked volitional control of the experimental limb. Six were complete and two were incomplete SCI (T4-T10).

Laboratory instrumentation: An isokinetic exercise device (LidoActive Loredan Biomedical) measured angular position, velocity and moment during knee exercise. Analog signals were sampled by an IBM PC/AT system for calibration, gravity compensation and data acquisition. ES was generated by a printed circuit board in the IBM system. Asymmetrical biphasic pulses (350 uS, 33 pps) were used. Amplitude modulation was employed during closed loop exercise to maintain knee extension moment (KEM) within ±2 Nm of the target. Self-adhearing electrodes (Pals Flex, Axelgaard Mfg.) were employed for laboratory and home use (3x5 cm). Home stimulation: A portable, eight channel ES system provided asymmetrical or symmetrical biphasic pulses (300-350 uS, 33-100 pps) at 0-150 mA. Pulse width and/or pulse amplitude modulation were available for ramping up or down. Duty cycle and ramp (1-200 pulses) were programmable.

Procedure: SCI subjects exercised with ES for 2 hours/day at home and came to the laboratory two or three times weekly (8-12 weeks) for work-goal oriented exercise. During laboratory exercise, KEM provided feedback for stimulus amplitude adjustment to maintain the target force production. Knee range of motion was limited to 10-80 degrees. Laboratory ES exercise was continued on each visit until the KE work performed exceeded the previous exercise session.

Repeated measurement of peak KEM, work production and fatiguability documented change. Closed-loop ES fatigue curves (maximum contraction over 40 knee extensions, 60 deg/sec) demonstrated peak KEM and several indices of fatigue. Maximum work performed prior to fatigue was considered in relation to the resistance to passive knee motion (5-230 deg/sec) on the same test day.

## Results

Peak KEM, total work performed and fatigue resistance improved significantly as a result of the FNS exercise protocol ($p<.01$). Although subjects varied in body size and gender, all but one subject achieved greater than 40% of predicted isokinetic knee extension peak moment at 60 deg/sec. Improvements in peak KEM were associated with a reduction in interfering hamstring spasticity and with the ability to utilize greater current intensity as joint crepitus and spasticity diminished over the weeks of FNS exercise.

Alterations in FNS muscle performance during the ES protocol varied among subjects as a result of differences in sensory and reflexive status. 3 subjects were chosen to demonstrate variability in FNS responses. The first was a T6 complete paraplegic with no sensation or motor control in the lower limbs. At 17 years after SCI, spasticity was present but did not limit passive knee movement or interfere with ES knee motion.

| Subject 1 | Pre FNS | Post FNS |
|---|---|---|
| Peak Moment Nm | 50 | 65 |
| Total Work (Nm-deg) | | |
| 40 reps | 722 | 1182 |
| 75 reps | 1078 | 2511 |
| % Peak Moment | | |
| Rep 7 | 90 | 98 |
| Rep 40 | 28 | 46 |
| # Reps to 50% Peak KEM | 26 | 38 |

Improvement in peak KEM and work values were associated with the use of greater stimulus amplitude as knee crepitus decreased (Fig 1).

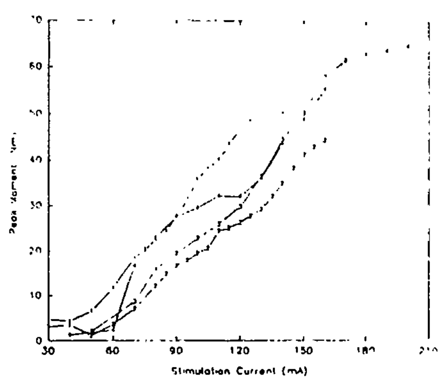


Fig 1. KE recruitment curves (60 deg/S). 1=pre FNS, 4=end FNS. Reduced knee crepitus permitted higher amplitude (>150 mA). The shift to the right by 3 weeks (2-2) may reflect reduced quadriceps spasticity.

Subject 2 was a T10 incomplete paraplegic with severely impaired sensation and no motor control. At 18 years after SCI, moderate spasticity interfered with function and limited knee movement. Daily change in spasticity contributed to marked differences in muscle performance in the early weeks of FNS exercise. The magnitude of day to day fluctuation diminished over time (Fig 2). Improvement in ES peak moment and work values was associated with improved knee crepitus and the use of greater stimulus intensity as well as reduced interference from quadriceps and hamstring spasticity.

| Subject 2 | Pre FNS | Post FNS |
|---|---|---|
| Peak Moment (Nm) | 24 | [illegible] |
| Total Work (Nm-deg) | | |
| 40 reps | 424 | 1291 |
| 75 reps | 632 | 2124 |
| % Peak Moment | | |
| Rep 7 | 77 | 93 |
| Rep 40 | 72 | 57 |
| # Reps to 50% Peak Moment | 26 | 38 |

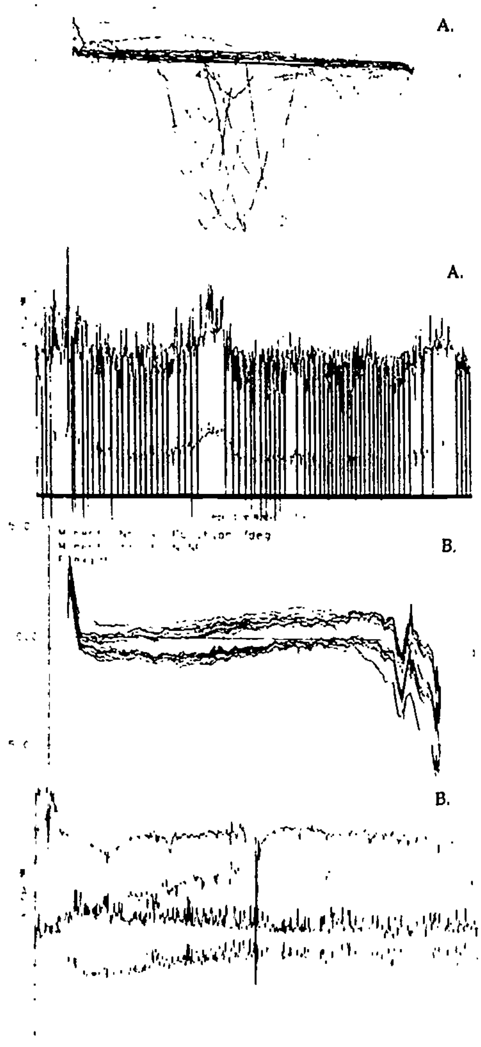


Fig. 2. A. Pre FNS: quadriceps spasticity documented as KEM during passive knee flexion (5 deg/S). Hamstring spasticity seen as flexion moments during KE. 70/539 KE repetitions altered by spasticity during FNS exercise. B. Post FNS: spasticity minimal (5 deg/S) and 1/462 KE repetitions altered by spasticity.

Subject 3 became a T10 incomplete SCI 12 years ago. She retained almost normal sensation but no motor control in the experimental (left) lower limb. Spasticity was mild. Discomfort was a major limiting factor in FNS force production. Pulse width was adjusted to begin ramping at 100 uS (vs 10 uS) and pulse repetition rate (ppr) was increased to 50 pps to improve comfort. Mental effort to assist FNS knee extension improved current tolerance.

| Subject 3: L<br>No vol motor<br>+ sensation | Pre FNS | Post FNS |
|---|---|---|
| Peak Moment (Nm) | 21 | 42 |
| Total Work (Nm-deg)<br>40 reps<br>75 reps | <br>437<br>Unable | <br>949<br>2066 |
| % Peak Moment<br>Rep 7<br>Rep 40 | <br>76<br>50 | <br>82<br>69 |

FNS exercise was also used in this subject's right leg in which she had minimal quadriceps control (Trace) and impaired sensation. She could activate spasticity to augment her trace muscle. Voluntary effort combined with ES improved her muscle performance.

| Subject 3: R<br>Trace motor,<br>- sensation | Pre FNS | Post FNS |
|---|---|---|
| Peak Moment (Nm)<br>Vol<br>ES (Max tol)<br>Vol + ES | <br>12<br>22<br>37 | <br>16<br>44<br>69 |
| Total Work (Nm-deg)<br>Vol + ES<br>40 reps<br>75 reps | <br><br>484<br>495 | <br><br>1483<br>1943 |
| % Peak Moment<br>Vol + ES<br>Rep 7<br>Rep 40 | <br><br>70<br>31 | <br><br>90<br>38 |

## Discussion

The diversity demonstrated in this sample is reflective of the clinical findings in SCI. If the scope of therapeutic and functional electrical stimulation is to be expanded to include the large number of incomplete patients, the uniqueness of each patient must be appreciated. All subjects improved in muscle performance as a result of the FNS protocol. Improved fatigue resistance was reflected in the maintenance of knee extension moment over a greater number of muscle contractions. Subjects were able to maintain useful knee extension force for up to 600 repetitions at a rate that simulates the normal gait cycle duration (rest interval of 1.5 seconds). The consistent improvement in force maintenance over the first 7 repetitions may reflect a shift toward a more oxidative profile as a result of the FNS protocol. Reduction of interfering spasticity contributed to improved peak moments and work, as well as reliability of FNS muscle contraction. Increased peak knee extension force also was associated with reduced knee symptoms and increased investigator comfort in applying greater stimulus intensities. This is in contrast to study designs in which peak moment limits are pre-determined for this osteoporotic patient group. The stimulus modifications necessary to make stimulation tolerable to patients with sensation are noteworthy. The majority of SCI, and other, patients retain some sensation. The ability to select ramp strategies, prr and pulse duration is critical to success. Minimal volitional muscle contraction may be useful in combination with FNS to augment the incomplete patient's muscle performance.

## Conclusion

The closed-loop, work-goal exercise regimen used in this project, combined with a sub-maximal, home exercise protocol resulted in both increased peak KEM and fatigue resistance. The improvements were both statistically and clinically significant when referenced to daily functional demands. The success of FNS protocols is contingent upon comfort of the exercise for patients with sensation. These findings have application to the rehabilitation of SCI patients and to the use of FNS systems for limb function.

## Acknowledgements

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Joyce M. Campbell, Ph.D., P.T.
Rancho Rehabilitation Engineering Program
7503 Bonita Street
Downey, CA 90242

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# NUCLEUS FES-22 STIMULATOR FOR MOTOR FUNCTION IN A PARAPLEGIC SUBJECT.

Ross Davis*, Janus Kuzma#, James Patrick#, James W.Heller#,
James McKendry•, Richard Eckhouse**, and Sandra E.Emmons*.
*Neurosurgery, • Orthopedics, Kennebec Valley Medical Center, Augusta, ME; **Math &Computer Science, U. Mass. Boston, MA; #Cochlear Pty. Ltd., Nucleus Group, Lane Cove, N.SW., Australia.

**Abstract**: The "Cochlear Mini-22" channel implantable cochlear stimulator (Cochlear Pty. Ltd., Nucleus Group, Lane Cove. N.S.W., Australia) has been modified into a functional electrical stimulator ("Nucleus FES-22") by re-engineering and computer programming. Initially in 1985, it was used for animal testing; then in 1991 it was redesigned for human implantation to stimulate upper or lower extremity motor-nerves. The implantable radio-receiver has connector ports for each of the 22 peripheral connector leads and electrodes. Individual or multiple channels can be sequenced and adjusted for their individual pulse amplitude, width and frequency so allowing activation of single and/or multiple motor-nerves. The U.S. Food and Drug Administration has given an investigational device exemption to allow this system to be implanted in a paraplegic subject for bilateral lower extremity stimulation. In November 1991, a 22 year old paraplegic male was implanted with the system; the individual channel-electrode-nerve thresholds and maximum levels for each muscles contractions have been measured. These responses will be studied monthly for the first 6 months, before exercising and functional limb movements will be attempted.

## Introduction

Since Kantrowitz (7) in 1963 was able to raise a paraplegic subject into a standing position using FES through surface electrodes applied to the quadriceps muscles, problems of spastic reflexes initiated by skin surface stimulation and the lack of specificity plus the inability to penetrate to deep muscles in paraplegic subjects have been overcome by implanting stimulating electrodes directly onto peripheral nerves (10, 5, 2) or using deeply placed percutaneous wire electrodes to muscle motor points (9). In 1970 Willemon et al. (10) implanted epineural cuff electrodes onto the femoral and inferior gluteal nerves in a complete T-5 paraplegic subject who was able to stand in the erect posture. In 1972, Davis and Gesink (5) implanted a T-5 paraplegic subject with bilateral peroneal nerve stimulators fitted with exercise groups increased in circumference by 24%. In 1973, Cooper et al. (2) implanted electrodes onto the femoral and sciatic nerves in a T-11 paraplegic to achieve walker assisted gait up to 40 feet. Brindley et al. (1) in 1978 was able to produce standing with crutches and "swing through" gait through a series of radio receiver-stimulating systems. Thoma et al. (6) implanted a radio linked 16-channel stimulator in 4 paraplegic patients in 1983. Following the training period the 4 subjects could walk 100 meters and stand for 20 minutes. Marsolais et al. (9) uses percutaneous wire electrodes to deliver precise patterns of sequencing through 32 channels of stimulations for standing, walking, and stepping for stair climbing; 6 of their 15 subjects were able to walk up to 250 meters. As a result, we were encouraged to develop an implantable 22-channel nerve stimulating system ("Nucleus FES-22") for control of the lower extremities in the paraplegic subject (3,4).

## Method

The FES-22 stimulator uses the same 2.5 Mhz radio-frequency (RF) link as the Mini-22 cochlear implant. This provides power and data to the implant. The FES-22 circuitry consists of two of the integrated circuits used in the Mini-22 device. These circuits are connected in parallel to provide increased output current. The implant case is cylindrical with a diameter of 80 mm and thickness of 30 mm. It is made of molded epoxy. There are 22 sockets around the periphery for connection of the electrode leads.

The external system used to program the implant is also similar to that used for cochlear prostheses. An IBM compatible personal computer is used to control stimulation. The computer interfaces with a wearable signal processor through two printed circuit boards in the computer and an external interface box. The wearable signal processor is a cochlear implant speech processor modified for increased RF output. Specialized software has been written to measure and store the muscle name, threshold level, maximum stimulation level and desired stimulation level for each electrode. The program also allows for ON/OFF cycling of individual electrodes as well as sequencing of combinations of electrodes, adjustments can be made for their individual pulse amplitude, width and frequency. The maximum output of the stimulator is 4.30 milliampere, at 400 msec pulse width (balanced pulse).

A 22 year old male was rendered completely paraplegic in an ATV accident in 1986. He underwent a conditioning program. For one year prior to the implantation he has been stimulating the quadriceps and the peroneal nerves bilaterally with stimulating with the "Respond" external stimulator (Medtronic, Inc., Minneapolis, MN). After several weeks of slow conditioning his muscle contractions were considered quite strong and as a result he became a candidate for the implantation of the FES stimulator. In November 1991, he started the first of 3 operations which were spaced 2 weeks apart with a total operating time of approximately 20 hours. After the wounds had healed and the tissues stabilized he was tested through the radio receiver for each of the 20 motor nerves that were implanted with the electrodes. The testing took place on January 3, 1992.

There were 20 out of the 22 available electrode lines implanted on 10 nerves in each lower extremity and they were placed almost symmetrically. There are 20X 60 cm connecting leads from the radio receiver down to the electrode sites. The electrodes had various lengths of lead to connect so that they could accurately reach the nerve for their attachment. The nerves were not disturbed and were not dissected if possible. The 2.5 mm platinum disc electrode were placed on the surface of the nerve to obtain the best threshold and maximum responses. The outer silastic rim around the electrode was sutured with 6'0' to 7'0' nylon sutures to the adjacent tissues. The femoral nerve distribution, as well as the sciatic nerve distribution were relatively easier to implant when compared to the superior and inferior gluteal nerves which required more charge to initiate a muscle response.

The following muscles had an electrode attached to their motor nerve: - rectus femorus, the 3 quadricep muscles, the superior and inferior gluteal nerves, the semimembranosus/tendinosus, the peroneal and tibial nerves.

When each electrode became a cathode to stimulate the other 19 electrodes became the anode for return pathway of the current.

## Results

The surgical procedure was considered a learning experience. There is at this time no indication of any infection. The blood count and urine were examined in the laboratory on January 3, 1992 without any indication of infection. At the first operation the radio receiver was implanted on the right side of the lower costal margin and since he had a level of sensation below this he was anesthetized for the first procedure. During the first procedure the femoral nerves and their branches were implanted. The second procedure was the implantation of the right posterior nerves including gluteal and sciatic branches. The third procedure was on the left lower extremity with similar nerves implanted.

The threshold of stimulation as of January 3, 1992 showed that 10 nerves had less then 1 mA as their threshold at 200 msec pulse width stimulating at 30 pulses per second. Three nerves had thresholds at 1.0 to 1.5 mA. One nerve required 1.90 mA, another nerve required 2.0 mA and 5 nerves required between 3 and 4.3 mA to initiate their movement. These were principally the gluteal nerves and the muscles themselves were not giving a very strong response at the time of surgery.

For maximum contractions the current levels were as follows. Three nerves reached their maximum at between .55 and 1 mA. Six nerves reached their maximum between 1.0 and 2.0 mA. Three nerves reached their maximum between 2.1 and 3.0. Eight nerves reached their maximum between 3.1 and 4.3 mA. The electrodes for 2 future nerve attachments are in place in the medial thigh and this will be a decision made in the next year as to whether to connect them to the obturator nerve.

## Discussion

The feasibility of modifying a presently widely used Cochlear implant into a functional electrical stimulator for the control of paralyzed extremities has been attempted. The surgical procedure so far appears practical. It will be important over the next 4 to 5 months to know that the electrodes remain in close contact with the nerves and that the thresholds and maximum values are maintained. Quantitative measurements of muscle movement and strength will be obtained. Also further use of pulse width will be done to bring weaker muscles into stronger contractions.

## Acknowledgements

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Ross Davis, M. D.
Kennebec Valley Medical Center
55 Middle Street
Augusta, Maine 04330

# The Use of a Powered Orthotic Device to Aid Individuals with a Loss of Bipedal Locomotion

John E. Beard, Michigan Technological University; James C. Conwell and D. Scott Rogers, Louisiana State University; and Mary-Nell Anderson, Ochsner Clinic of Baton Rouge

## ABSTRACT

A recent study of the current methods to restore gait to patients suffering from permanent below waist paralysis indicates the majority of biomechanical research for below waist paralysis can be characterized into two areas: functional neuromuscular stimulation (FNS), and mechanical synthesis type devices. This paper is the description of a powered exoskeleton that provides a $C_2I$ with bipedal locomotion. The synthesis of the mechanism plus the determination of an "acceptable gait" is described.

## NOMENCLATURE

$TR_G$ = $\frac{\text{\% of cycle from standing to heel strike}}{\text{\% of cycle from heel strike to standing}}$

$\theta_{Hip}$ = angle of the thigh relative to the torso.

$\theta_{Knee}$ = angle of the shank relative to the torso.

$\Delta\theta_{Hip}$ = maximum rotation angle of the thigh relative to the torso.

## INTRODUCTION

To test the potential of lightweight, power assisted orthotic devices to aid individuals with a loss of bipedal locomotion, a prototype device was constructed that provides both powered hip and knee flexion. The powered gait orthosis (PGO) was tested to determine if:

A) A lightweight PGO was technically feasible from the power/energy requirement.

B) A paraplegic or quadraplegic would be able to ambulate with minimal or no external assistance.

C) A PGO would be economically viable.

The design of the mechanical/electrical portion of the problem required quantification of what type device was needed for the range of injury, patient skill, etc. Rehabilitation physicians and physical therapists interviewed paraplegics and quadraplegics to establish the minimal external assistance needed to help them walk. It was determined that an orthotic device providing the power to move the leg through the step would remove a signficant barrier to bipedal locomotion. Because external support was provided, an active control system to balance the user was not needed. This enabled the investigators to concentrate on the design and analysis of a powered gait orthosis (PGO) capable of walking an individual on a smooth, level surface. The power requirements needed were based on the power exerted by an individual during normal walking (1). Although the investigators realized that a PGO would probably require more energy from the power source, a Ni-cad battery for this prototype, this assumption was used to establish a minimal output power requirement for the device.

Patients selected for the study had vastly different injuries. A brief summary of a particular patient is as follows:

Subject I1 is a 20 year old male. He is a C2 incomplete quadriplegic secondary to a diving accident that occured in 1986. He also suffered a head injury that impared his cognition. His motivation was excellent and he had previously been minimally successful with the RGO.

To synthesize a mechanism that would provide the desired walking motion, first an acceptable gait was needed from which a function could be determined. First examine "normal" walking where normal walking is defined by Inman (2) as *"The term walking is nonspecific. Its connotation is that of a cyclic pattern of bodily movements that is repeated over and over, step after step. Consequently, descriptions of walking customarily deal with what happens in the course of just one cycle, with the assumption that successive cycles are all about the same."* Figure 2 shows the hip angle and shank angle versus the percent of the cycle for an adult male. It was shown by Townsend, et-al (3) that walking can be represented by a periodic function that is the sum of polynomial and Fourier series. A Fourier series was used to define the hip angle versus percent of cycle as shown in Figure 2. Although normal gait can be represented by a function no technical definition of an acceptable gait function for a paraplegic was available, however, Riegel, et-al (4) proposed a rather loose technical definition of gait as "anything that worked."

Because the goal is to help a paraplegic regain bipedal locomotion, both patient and physician will accept most any gait that is safe and moves the patient, however this definition is not sufficent for the purpose of kinematic synthesis. By examining traditional patient powered orthoses, minimal kinematic parameters were determined. The three degree of freedom hip joint and six degree-of-freedom knee joint of the human body could each be constrained to a one degree-of-freedom joint and still approximate normal walking. The orthosis has revolute joints at both the hip and knee with their axes of rotation normal to the sagittal plane. In the sagittal plane there are three important parameters of the gait to be emulated. They are:

- The time ratio of the gait, $TR_G$.
- $\Delta\theta_{HIP}$, the magnitude of the rotation of the hip relative to the torso.
- Foot trajectory (path) in the sagittal plane (the foot is rigidly attached to the shank and does not rotate relative to the shank).

The biomechanical implication of the time ratio of the gait, denoted as $TR_G$, is the ratio of the time the foot is unsupported to the time the foot is in contact with the floor. Experimental results from six adult males walking at various speeds were used to establish initial time ratio ranges. The tests had time ratios that varied from 0.98 to 1.27.

Although normal walking varies from individual to individual and there is not one correct function for a group or even an individual the time ratio, $\Delta\theta_{Hip}$, and foot trajectory can be viewed as an invariant during the initial design phase. To design the PGO first examine the plot of the hip angle ($\theta_{Hip}$) versus the percent of cycle shown in Figure 2. The Fourier series used to approximate both the hip and knee are

$$\begin{aligned}\theta_{Hip} = {} & 293.50° - 18.18\cos(2\pi X) - 2.74\cos(4\pi X) \\ & -0.67\cos(6\pi X) - 0.94\cos(8\pi X) \\ & +0.16\cos(10\pi X) + 10.096\sin(2\pi X) \\ & -5.28\sin(4\pi X) + 1.43\sin(6\pi X) \\ & -0.98\sin(8\pi X) + 1.46\sin(10\pi X) \qquad (1)\end{aligned}$$

and

$$\begin{aligned}\theta_{Knee} = {} & 271.45° - 8.07\cos(2\pi X) + 6.79\cos(4\pi X) \\ & -3.86\cos(6\pi X) + 2.22\cos(8\pi X) \\ & -19.04\sin(2\pi X) + 2.22\sin(4\pi X) \\ & -0.98\sin(6\pi X) + 0.59\sin(8\pi X) \qquad (2)\end{aligned}$$

where $0.00 \leq X \leq 1.00$. Time ratios observed from experimental data (5) ranged from 0.84 to 1.27 and $\Delta\theta_{Hip}$ ranged from 30° to 54°. The gait function to be emulated was determined from experimental data obtained using instrumented linkages from "normal" walking in a controlled environment (5,6).

In normal walking the individual starts in a monopedal period. Once each leg has completed a cycle the individual is now in bipedal motion. The user of the PGO starts in a monopedal motion with both feet together, takes one step, moves the stability aid (crutches or walker) and then moves the other leg. Therefore, as the individual walks using the PGO, they have both feet together at the beginning and the end of each step. This motion is a combination of the monopedal and bipedal phase and requires an increased pelvic lift so the foot will clear the floor. The energy expenditure for this form of modified walking is greater than "normal" walking even though all energy to move the lower limbs is provided by the PGO.

## CONCLUSIONS

A $C_2I$ quadriplegic tested the PGO. A 200 watt motor with an output velocity of 17.5 RPM was sufficient to power the hip and knee. The provided a maximum gait speed of 17.5 steps/minute. The peak power measured was 91 watts. The average walking speed of the user in the PGO is 12 steps/min. (each step is 0.3 m). The normal walking speed of the same size person is 60 steps/min to 90 steps/min (each step is 0.75 m). The walking speed of the user in the PGO includes the time necessary to move the secondary means of balance.

One of the initial goals of the project was to determine the practically of the PGO concept. The PGO was successful in demostrating the potential of lightweight, self-powered, exoskeletal devices to restore bipedal locomotion.

## ACKNOWLEDGEMENTS

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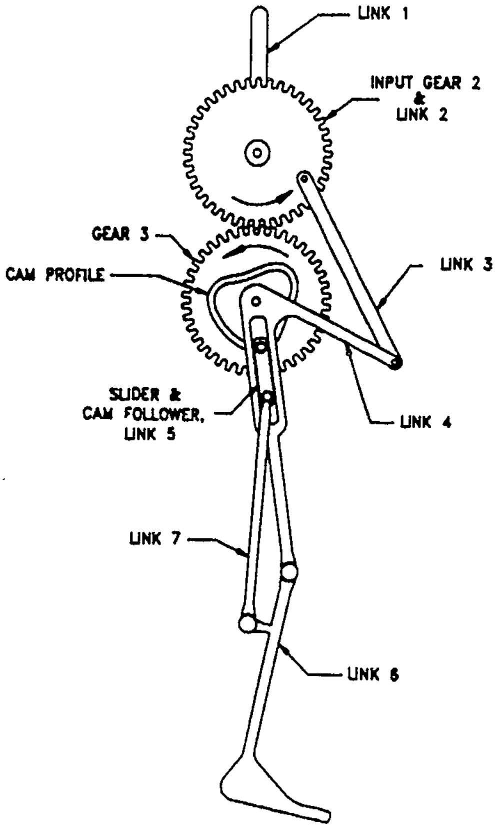


Figure 1. The skeleton diagram of the PGO.


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Dr. John E. Beard
ME-EM Department
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931


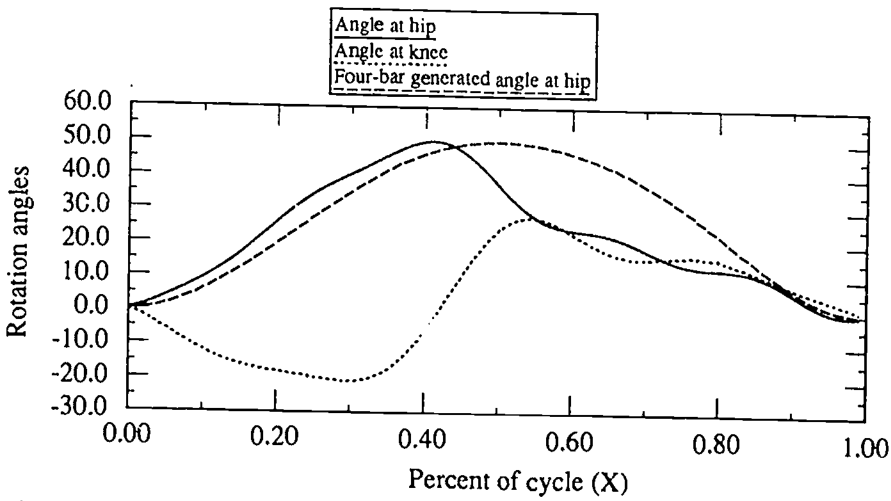


Figure 2. The Fourier representation of the hip and knee angles plus the angle generated by the four-bar used to power the hip.

# TOTAL POWER OUTPUT MEASUREMENT DURING FES LEG CYCLE ERGOMETRY

Stephen F. Figoni, Roger M. Glaser, Mary M. Rodgers, and Steven R. Collins

Veterans Affairs Medical Center, and Institute for Rehabilitation Research and Medicine,
Wright State University School of Medicine, Dayton, Ohio, USA

## ABSTRACT

The purposes of this study were: 1) to determine the magnitude of *unmeasured* power output (PO) during exercise with the "ERGYS" functional electrical stimulation leg cycle ergometer (FES-LCE), and 2) to estimate the *actual total PO* at each resistance increment with the ERGYS. Sixteen spinal cord injured individuals performed steady-rate exercise tests providing aerobic energy expenditure (oxygen uptake, $\dot{V}O_2$) data at rest, during fully assisted FES-LCE ("true 0-W"; i.e., passive pedaling maintained by a constant-velocity motor), during FES-induced LCE at 0-W (unloaded), and during FES-induced 6.1-W LCE. The increase in $\dot{V}O_2$ was found to be 0.172 L/min when the ERGYS PO was increased from 0 to 6.1-W (i.e., from 0 kp to 1/8 kp load resistance indicated). The difference in $\dot{V}O_2$ between the 100%-assisted ("true 0 W") and the indicated 0-W stage was 0.220 L/min. By extrapolation, the 0.172-L/min $\dot{V}O_2$ increase for the 6.1-W PO increase showed that the 0.220-L/min $\dot{V}O_2$ increase from true 0 W to the indicated 0-W PO represents the equivalent of 7.8 W of unmeasured PO. This unmeasured PO may be due to factors such as internal friction of the device, limb weight, viscosity/ friction of muscles, and joints, and limited range of motion. Therefore, 7.8 W may be added to each indicated ERGYS PO level to reflect the actual total PO.

## INTRODUCTION

The "ERGYS I" (Therapeutic Technologies Inc., Tampa, FL) is a leg cycle ergometer (LCE) driven by functional electrical stimulation (FES) of paralyzed leg muscles. The primary objective of this medically-prescribed FES-LCE exercise therapy is to improve aerobic/cardiovascular physical fitness in order to prevent/reverse multisystem physiological deterioration and disuse atrophy after spinal cord injury (SCI). Peak metabolic and cardiopulmonary responses during FES-LCE have been shown to increase significantly above rest in SCI individuals during exercise testing, and substantial gains in fitness have been realized following training programs [1,2].

Power output (PO) during FES-LCE can be computed from the cycling cadence (rpm) and the resistance load or frictional braking force (kp) electronically applied to the flywheel: PO = kp x rpm x 0.98, where 0.98 is a constant converting the PO units from kpm/min to W (6 m/flywheel revolution / 6.12 kpm/min/W). For example, standard calculations will show that a typical ERGYS user cycling at an indicated 1/8-kp resistance and 50-rpm cadence is performing at a PO of 6.1 W. Resistance and cadence on the ERGYS may range from 0 (unloaded flywheel) to 7/8 kp and from 35 to 50 rpm, respectively. Therefore, PO may range from 0 to 42.7 W. However, ERGYS users typically use the lower PO levels (i.e., 0-12.2 W) for endurance exercise, especially if they are not highly trained [3].

Since most ergometers (including the ERGYS) measure PO at the internal braking force mechanism, it excludes PO attributable to several sources of resistance/friction which must be overcome to perform active exercise. For FES-LCE operation, sources of unmeasured resistance/friction (internal and external) include the chain, sprockets, bearings, ankle-foot orthoses, leg guides that prevent excessive hip rotation, and characteristics of the user such as leg weight, muscle spasticity; muscle, joint and fluid viscosity/friction; and possibly restrictive influences of clothing, electrodes, adhesive tape, seat surface, and joint inflexibility [4]. Thus, the ERGYS does not measure the *actual total PO* performed by the individual. This actual total PO is higher than that indicated by the ergometer since several components of unmeasured work are not included in the calculation [5,6].

Since the physical capability of untrained SCI individuals during FES-LCE is relatively low, it would be desirable to know the *actual total PO*. Therefore, the purposes of this study were 1) to determine the magnitude of unmeasured PO during FES-LCE with the ERGYS using an extrapolation technique, and 2) to estimate the actual PO at the indicated O kp resistance, as well as the additional PO required to perform each 1/8-kp resistance increment above 0 kp. Such information is important for more complete physiologic and mechanical analysis of this exercise, and it would help guide further engineering analysis of this device.

## METHODS

Subjects

Sixteen chronic SCI individuals served as subjects for this study. The average age was approximately 34 years (range: 20-51 years); two were female and fourteen were male; nine were paraplegic (SCI levels $T_4$-$T_{11}$) and seven were quadriplegic ($C_5$-$C_8$). Subjects were trained sufficiently in FES-LCE to be able to complete the exercise test protocol.

Procedures

Subjects performed a continuous graded exercise test at 50 rpm pedaling rate using an "ERGYS" FES-LCE. Each stage of this test was 5-min in duration as follows: 1) rest, 2) passive cycling (subthreshold FES) where a technician turned the pedal manually, 3) constant velocity cycling where a motor was used to drive the flywheel and minimal FES was used to achieve the target velocity ("100% assist", true 0-W PO), 4) FES cycling where the motor performed 50% of the PO, and 5) FES pedaling at 0-W PO as indicated by no flywheel resistance load. Steady-rate $\dot{V}O_2$ values were determined by open-circuit spirometry during the fifth minute of each stage. In addition, data are reported for these same subjects from a previous FES-LCE exercise test to provide $\dot{V}O_2$ data at 6.1 W as indicated by 1/8 kp flywheel load resistance.

To account for the unmeasured PO that is not accounted for by the flywheel resistance measurement, changes in the aerobic metabolic energy ($\dot{V}O_2$) that occurred at the various test stages were used. For this, the relationship between indicated PO and $\dot{V}O_2$ was determined. By knowing the difference in $\dot{V}O_2$ between 0 and 6.1 W indicated PO, the actual PO for "true 0 W" can be extrapolated from the $\dot{V}O_2$ level. Thus, the PO calculated from the ERGYS can be adjusted to take into account the unmeasured PO so that *true total PO* can be known.

## RESULTS AND DISCUSSION

All subjects completed all stages of the required exercise tests. Mean ± SE data for $\dot{V}O_2$ during each stage are presented in Table 1. Figure 1 illustrates the linear relationship between PO and $\dot{V}O_2$ for each test stage. Since we cannot directly measure all internal and external sources of resistance that contribute to the total PO, the metabolic effect of various exercise loads upon the subjects was used to obtain this information through indirect means. This method assumes that $\dot{V}O_2$ was not substantially affected by factors other than those related to performing the exercise.

**Table 1.** Mean ± SE oxygen uptake ($\dot{V}O_2$) responses and corresponding estimated total power output (PO) of spinal cord injured subjects (N=16) during FES leg cycle ergometry.

| Stage | $\dot{V}O_2$ (L/min) | Estimated Actual Total PO (W) |
|---|---|---|
| Rest | 0.190 ± 0.011 | --- |
| 100% Assist | 0.286 ± 0.019 | 0 |
| 50% Assist | 0.409 ± 0.021 | 3.9 |
| 0 W | 0.506 ± 0.031 | 7.8 |
| 6.1 W | 0.678 ± 0.040 | 14.0 |
| 12.2 W | | 20.1 |
| 18.3 W | | 26.2 |
| 24.5 W | | 32.3 |
| 30.6 W | | 38.5 |
| 36.8 W | | 44.6 |
| 42.9 W | | 50.7 |

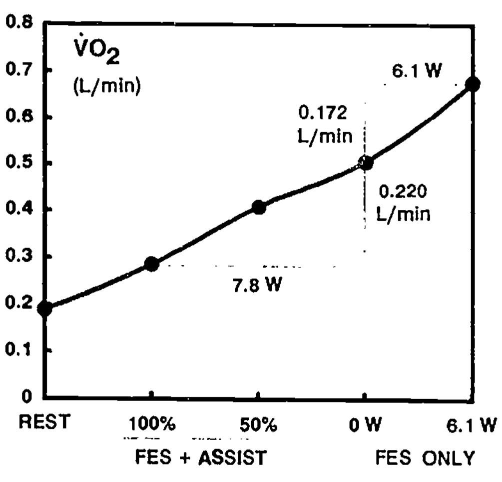


**Figure 1.** Relationship of oxygen uptake ($\dot{V}O_2$) to test stage during FES leg cycle ergometry for spinal cord injured individuals (N=16). The extrapolation to derive the power output (PO) from 100% assist to 0 W is shown.

The difference in $\dot{V}O_2$ between the "true 0-W" PO (100%-assist) stage and the FES cycling at the "indicated 0-W" PO stage was 0.220 L/min. The difference in $\dot{V}O_2$ between the "indicated 0-W" PO stage and the 6.1-W PO stage was 0.172 L/min. Since 0.172 L/min represents a 6.1-W PO increment, then by proportion, 0.220 L/min denoted that the actual PO at the indicated 0-W PO level is *7.8 W*. Thus, 7.8 W can be added to all indicated PO levels so that the actual total PO can be recorded.

Although a PO of 7.8 W is relatively low for able-bodied adults performing leg ergometry voluntarily (i.e., fit individuals can typically achieve 200 W PO), it represents a *major* portion of the PO that can be achieved by many SCI FES-LCE users. Indeed, most individuals initiate exercise at 0-W indicated PO and progress to 6.1 W in several weeks. In actuality, "true PO" would be about 14.0 W which is 128% higher than the indicated PO. Thus, to quantify their PO capability more accurately and to better chart their progress, this PO adjustment would be appropriate. During research and clinical assessments, SCI persons may require individual evaluation of total PO during FNS-LCE depending upon individual characteristics such as body size, spasticity, etc. Thus, actual total PO information may be useful to incorporate such testing into the evaluation process of each prospective FNS-LCE user. In addition, actual total PO information may facilitate further physiologic, biomechanical and engineering analyses of FES-LCE exercise.

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Stephen F. Figoni, PhD, RKT
VA Medical Center (151)
4100 West Third Street
Dayton, OH 45428

# DISTRIBUTED RANDOM ELECTRICAL NEURO-MUSCULAR STIMULATION: EFFECTS OF INTER-STIMULUS INTERVAL STATISTICS ON EMG SPECTRUM

**Y.T. Zhang[1], P.A. Parker*, W. Herzog[2], M. Hulliger[3], A. Guimaraes[2]**
**Departments of Elec. & Comput. Eng.[1], Biomechanics[2], and**
**Clinical Neurosciences[3], The University of Calgary, Alberta, Canada**
**Department of Elec. Eng., Univ. of New Brunswick, Fredericton, Canada***

## ABSTRACT

A distributed random electrical neuro-muscular stimulation (ENMS) of ten ventral root channels was used in this study to stimulate cat soleus muscle. The influence of varying inter-stimulus intervals (ISI) and the interaction of the ISI statistics with the compound motor unit action potential (CMUAP) on EMG power spectra were assessed theoretically using a mathematical model and experimentally using the data obtained from cat soleus muscle. Theoretical and experimental results suggest that (1) the interaction of the ISI statistics with the shape of the CMUAP significantly influence the EMG spectrum; and (2) that the EMG spectrum of electrical random stimulation of muscle shows peaks at the mean rate of stimulation and multiples of it when the ISI variation coefficient is small, and that these peaks decrease in magnitude with increasing frequency and increasing values of the coefficient of variation of ISI.

## I. INTRODUCTION

For ENMS to work satisfactorily in a given situation, it is necessary to select proper stimulation parameters and employ stimulation strategies in accordance with findings from research in electrophysiology. A literature review of electrophysiological studies of muscle identifies the following important points [1,2,4,5,8]:1) voluntary contraction of skeletal muscle is controlled by the number of motor units, which are progressively recruited according to the size principle, and the rate of firing of each unit; 2) Signals from active motor units are uncorrelated during low and medium voluntary efforts, and become synchronized at high efforts; and 3) Firing of alpha motor neu ons is a random process, i.e., the time interval between two successive spikes is a random variable described by a probability density function (pdf). These random firing patterns of motor units have been widely studied during voluntary contractions in human skeletal muscles [1,2,4,7,9].

Partly due to technical difficulties and partly due to lack of adequate information, early research involving ENMS did not adequately represent the actual physiologic situation. In the 1970s some researchers started to incorporate physiological findings into research using ENMS. Working on the lower leg of the cat, Petrofsky described a computer-controlled stimulator and special electrode array, which could control the recruitment pattern of motor units during electrical stimulation [10]. More recently, a neuro-muscular stimulation system was introduced that can be used to change forces in skeletal muscle by varying motor unit firing rate and recruitment control strategies [11]. Using this system, the relation between force and EMG has been carefully studied. However, with only a few exceptions [6], these studies did not consider that the inter-spike interval (ISI) (in the case of stimulation ISI represents the inter-stimulus interval) is random.

In this study, we have used a distributed and random neuro-muscular stimulation scheme which allowed to control the recruitment of motor units and the ISI statistics. The power spectrum of EMG signal was chosen as an indicator on how well the EMG produced by the ENMS compared to that of voluntary contractions. Since it is difficult to evaluate each possible ISI modification experimentally, a mathematical model was used to predict the EMG spectrum of a given stimulation design. Results of the theoretical analysis were compared to experimental results obtained using distributed random ENMS of 10 ventral root filaments of cat soleus muscle. In this paper, emphasis will be placed on the effects of the ISI statistics and its interplay with the CMUAP on the EMG spectrum. This work provides information of reproducing 'normal' muscle activation, under which meaningful EMG-force relationship can be studied.

## II. SPECTRAL EXPRESSION FOR DISTRIBUTED RANDOM ENMS

The idea of distributed random ENMS results from electrophysiological findings [4,8,9]. In this section we use a structural model to investigate systematically how ISI patterns and the CMUAP interplay in reproducing EMG spectrum. In the structural model, $u_i(t)$, $i = 1, 2, ..., m$, is the stimuli signal train, which corresponds to the innervation signal for the fibers of the ith channel and is considered, as in physiological case, a renewal point process with known ISI pdf $f_{xi}(x)$ [3]. With uncorrelated channels, the power density spectrum (PDS), $\Phi_{yy}(f)$, is given by

$$\Phi_{yy}(f) = \sum_{i=1}^{m} \lambda_i \left( 1 + \frac{F_{xi}(f)}{1 - F_{xi}(f)} + \frac{F^*_{xi}(f)}{1 - F^*_{xi}(f)} \right) |P_i(f)|^2, \; f \neq 0 \qquad (1)$$

where the superscript * represents the complex conjugate, $m$ is the number of stimulation channels, $F_{xi}(f)$ is the Fourier transform of the ISI pdf $f_{xi}(x)$, $P_i(f)$ is the Fourier transform of the CMUAP in the ith channel, and $\lambda_i$ is the stimulation rate (SR) of the ith channel. The formulation given by Equation 1 indicates that the EMG spectrum of simultaneous distributed ENMS is the sum of the spectra of the individual channels. It is clear that the spectrum of EMG signals depends not only on the spectrum $P(f)$ of the individual CMUAP, but also on the ISI pdf $f_{xi}(x)$.

Since a Gaussian distribution of inter-spike intervals has been reported previously [2], we adopted this distribution model for producing ENMS involving random stimulation. With $f_x(x)$ a Gaussian distribution and the same ISI variance across all stimulation channels, we have from Equation 1,

$$\Phi_{yy}(f) = \sum_{i=1}^{m} \lambda_i \frac{\sinh[2(\pi f \sigma_x)^2]}{\cosh[2(\pi f \sigma_x)^2] - \cos(2\pi f/\lambda_i)} |P_i(f)|^2, f \neq 0. \quad (2)$$

where $\sigma_x$ is the standard deviation of the ISI. Equation 2 indicates the following points: (1) depending on the variance of the ISI, the power density spectrum $\Phi_{yy}(f)$ may or may not show peaks at harmonics of the firing rate; (2) the strengths of the peaks induced by the firing rate depends on the ISI variation coefficients defined by $c = \sigma_x \lambda$; and (3) the PDS progresses towards a line spectrum when $\sigma_x \to 0$.

## III. ENMS ON CAT SOLEUS MUSCLE

In vivo measurements of EMG signals were obtained from cat soleus muscle. The cat was anesthetized and placed in a stereotactic frame in a prone position with its hind limbs rigidly locked to the frame. Ventral roots L7 and S1 were exposed, separated from one another, and carefully divided into bundles. Each of these bundles was hung over a separate bipolar electrode for individual and simultaneous distributed stimulations. The stimulations using patterns generated from computer simulation were applied to the ventral root filaments via the electrode. EMG signals from stimulations of each of the ten nerve bundles individually (finger prints) and simultaneous stimulation of all ten channels were measured using a pair of indwelling electrodes. EMG signals were digitized on line and stored on a computer. Blood pressure, core temperature and muscle temperature of the cat were monitored continuously and were kept constant throughout the experiment.

## VI. RESULTS AND DISCUSSION

For a given CMUAP, the spectrum of an EMG signal calculated using Equation 2 is plotted with m=1 in Figures 1 and 2 for different values of c. We can see from these figures that the influence of the ISI statistics on the PDS dominates the low frequency region, and that peaks are introduced at multiples of the SR (or firing rate), as observed experimentally by other investigators [7,9]. Such changes in the PDS induced by the ISI statistics may reflect variations in activation.

The power density spectrum of each experimental EMG signal was estimated using a 512-point fast Fourier transform (FFT) algorithm, and then averaged over four consecutive segments. Figure 3 gives two representative spectra of experimental EMG signals with the same μ and different values of c. These results strongly support the mathematical predictions discussed above and computer simulation results reported previously [12] that (1) the EMG signal spectrum shows peaks at the SR (or firing rate) and its multiples when the coefficient of the ISI variation is small; and (2) the PDS envelope is controlled by the CMUAP waveform and its details by the ISI stimulus statistics. As a conclusion, in ENMS studies, it is advisable to introduce variations in the inter-stimulus interval, in order to produce muscle behavior similar to that of voluntary contractions. Taken all observations together, the results suggest that ISI variation coefficients of between 5% and 35% are required in artificial ENMS experiments to obtain a result comparable to that of voluntary contractions.

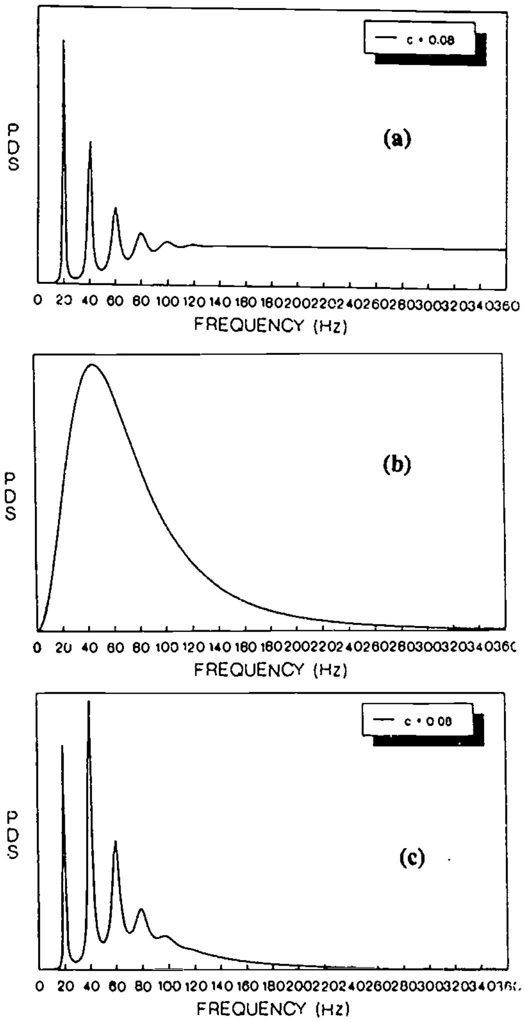


**Figure 1. (a) PDS of Gaussian point process with $\lambda = 20pps$ and $c = 0.08$, (b) $|P(f)|^2$ for the CMUAP, (c) PDS of the EMG signal.**

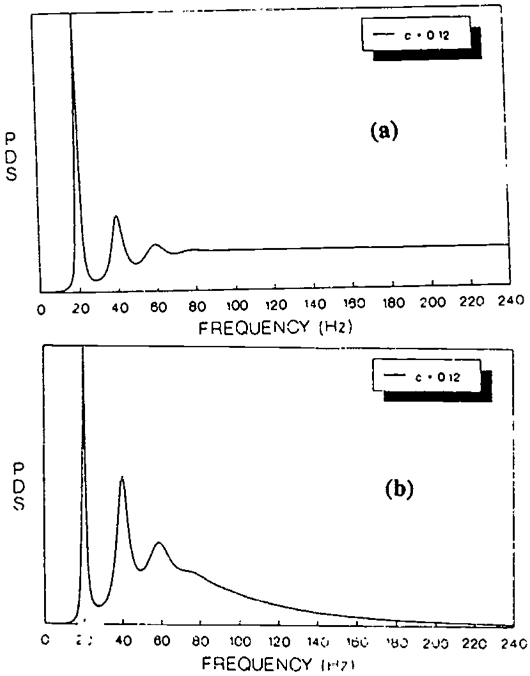


**Figure 2. (a) PDS of Gaussian point process with λ = 20 *pps* and c = 0.12, and (b) PDS of EMG signal with the same CMUAP as in Figure 1 (b).**

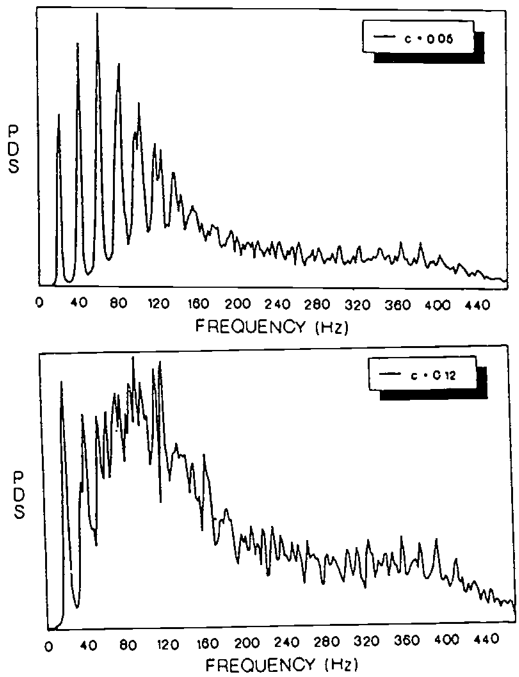


**Figure 3. PDS of EMG signals obtained from random ENMS with λ = 20 *pps* and different values of c.**

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Y.T. Zhang
Sports Medicine Center
The University of Calgary
2500 University Dr., NW
Calgary, Alberta, Canada T2N 1N4
Tel: (403) 220-4973

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# DETERMINING THE DIRECTION OF CRANK ACCELERATION DURING ELECTRICAL STIMULATION - INDUCED LEG CYCLE ERGOMETRY

L.M. Schutte, M.M. Rodgers*, B.N. Ezenwa*, R.M. Glaser* and F.E. Zajac

Mech. Eng. Dept., Stanford University and Rehab. R&D Center, VAMC, Palo Alto, CA
*Institute for Rehabilitation Research and Medicine, Wright State University and VAMC, Dayton, OH

Abstract

The purpose of this study was to explore the function of electrically stimulated muscles during leg cycle ergometry. A one degree of freedom model was developed which allows the direction of the acceleration resulting from a muscle torque acting at the knee or hip to be determined from geometric considerations. From this directional information, crank positions can be found where stimulation of a particular muscle will either help or hinder forward motion of the crank. These positions are compared for several different sets of geometries of the leg cycle ergometer. The theoretical results are also used to evaluate the stimulation patterns currently used in the commercially available ERGYS system[1]. Clinical FES systems, such as the ERGYS, typically use the same sequence of stimulation for all individuals. The results of this study suggest that this may potentially influence performance as the function of the stimulated muscles is not constant. Function varies with both the configuration of the ergometer and the size of the individual.

Introduction

Functional Electrical Stimulation (FES) induced leg cycle ergometry for spinal cord injured paraplegics and quadriplegics has been shown to provide a variety of therapeutic benefits, including the maintenance of paralyzed muscle integrity and the improvement of cardiovascular function (1). To maximize the effectiveness of FES system design, it is desirable to understand the expected mechanical function of the stimulated muscles. The movement that will result from a particular sequence of timings for the muscle stimulation may not be obvious, especially when two-joint muscles are involved or, as in cycling, the body and mechanical linkage being controlled form a closed kinematic loop. While there are many factors that affect this motion (e.g. the condition of the stimulated muscles, the recruitment characteristics of the stimulation, and the resistive load applied at the crank ), there is also a position dependent contribution a given muscle force makes to the acceleration of the crank that depends solely upon the physical dimensions of the system.

Individual muscle forces act to accelerate not only the segments to which the muscle attaches but also other segments in the system as well. This is an effect known as "dynamical coupling". Both the magnitude and direction of these accelerations may vary with position (2). Typically, the accelerations induced by a particular muscle force can be calculated from the equations of motion of a dynamical model of the system. Additionally, for leg cycling, geometric considerations alone, allow the ***direction*** of this acceleration to be determined.

[1]ERGYS, Therapeutic Technologies, Inc. Tampa, FL.

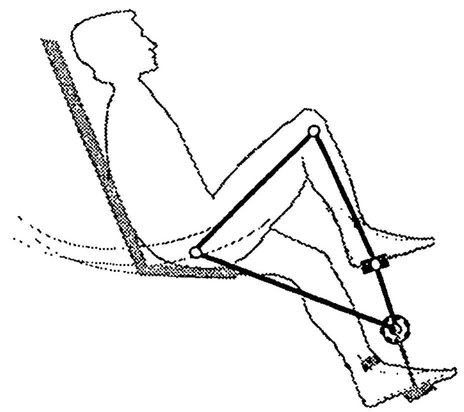

*Figure 1. Singularity configuration in the right leg four-bar linkage of pedaling model.*

Method

Pedaling with muscle forces generated by FES induced contraction typically involves constraining the ankle with an orthosis. Under these conditions, an appropriate model of cycling consists of two planar four-bar linkages coupled through the crank. Each leg is composed of four links: the thigh, shank and crank, and a fixed segment connecting the crank center to the hip. Four-bar linkages display the useful property that when one angle is specified, all the remaining angles are determined (3). For the case of cycling, the crank segments in each of the two, four-bar linkages are fixed $180^{o}$ relative to each other. Thus, the total system has a single degree of freedom.

The direction of the acceleration of the crank due to either a torque applied at the hip or knee can be determined by analysis of the geometry of one of the four-bar linkages contained in the one degree of freedom model. Each four-bar linkage contains four positions where two of the links become collinear. At these positions, there is a change in the direction of the motion of one of the joints from flexion to extension, or from extension to flexion. A singularity in the acceleration caused by the muscle crossing that joint also results. For example, consider the configuration of the right leg shown in Figure 1. The crank is in line with the shank and the hip is in its most flexed position. Now, consider a flexion torque applied at the hip. In any position this torque will attempt to increase the angle of the thigh and move points at the knee and crank center away from each other. Intuitively it can be seen that in most other crank positions this would cause the crank to rotate either in a forward or backward direction depending on the precise position of the crank. In the singularity position illustrated, however, the distance between the knee and crank center is at its maximum and the torque cannot cause it to increase. No rotation of the crank will result. This position is a switching point for the direction of the acceleration of the crank due to the flexion torque at the hip. The direction of the acceleration switches back when the crank is again in line with the shank, and the hip is at its most extended position.

For a hip extensor, rather than a flexor torque, the switching points are the same, but the direction of the acceleration at other crank positions is opposite. Thus, the crank cycle can be divided into muscle function regions as shown in the small circles, labeled right and left hip, in Figure 2 . The equations for determining these switching positions (Appendix) are a function of the physical dimensions of both the ergometer and the subject.

Similar arguments for the remaining singular position, where the crank is collinear with the fixed segment connecting the hip and crank center, are used to determine the switching points for torques acting at the knee. The crank angles of these singular positions depend only on the orientation the fixed segment connecting the hip and the crank center and can be determined by inspection. Figure 2 shows how this information for both legs and all four joint torques can be overlaid to produce six divisions of the crank cycle corresponding to the six different combinations of muscle torques that accelerate the crank forward.

The stimulation patterns produced by the ERGYS controller for FES leg cycle ergometry are a function of both the velocity and position of the crank. The threshold level of the stimulation current can be individually set and the level of the stimulation current varies inversely with the performance produced by the stimulation. To determine the crank angle where each muscle is stimulated, the pedal crank rate was maintained at a constant 40 and 50 rpm by a velocity-controlled motor. The current pulse train was then sampled at 0.01 msec intervals.

Results and Discussion

The switching positions, as determined by the method above, correspond to changes in the function of an applied joint torque. Electrical stimulation results in a force development in a muscle or group of muscles which, in turn, results in a torque at the one or more joints crossed by the muscle. For gluteal muscles, contraction typically results in an extension torque at the hip. Thus, the crank positions where a hip extensor torque accelerate the crank forward also correspond to positions where stimulation of the gluteal muscle will have the same result. For a two-joint muscle, however, determining the resulting direction of acceleration is more complicated. For example, the hamstrings cross both the hip and the knee, producing an extensor torque at the hip and a flexor torque at the knee. At crank positions where each of these torques either accelerate the crank forward or backward, there is no ambiguity. Stimulation of this muscle will produce the corresponding acceleration of the crank. However, at positions where these two torques cause opposite acceleration, the actual direction will depend on both the relative magnitude of each of the torques and their relative effectiveness in producing acceleration. The relative magnitude of the hip and knee torque produced when a two-joint muscle is stimulated depends on the relative moment arms of the muscle at the two joints. For the case of surface stimulation, where it is difficult to stimulate a single muscle in isolation, it also depends on the relative amount of each muscle that is recruited by the stimulation.

The conclusions that can be made concerning the direction of the acceleration resulting from surface stimulation of gluteal, quadriceps and hamstrings muscle groups are illustrated in Figure 3. The exact switching locations depend on the physical dimensions of the system, namely the the limb lengths, the crank radius, and the length and orientation of the fixed segment between the crank and the hip. As shown in Figure 3, changing the dimension of any one of these will change how an individual muscle functions. Moving the seat forward, from the position of A in Figure 3 to C, results in an approximately $40^{o}$ increase in the range of crank positions where the gluteal muscles provide propulsion. It also increases by a similar amount the range where the function of the two-joint muscle groups is unambiguous.

Figure 4 shows these theoretical predictions of muscle function compared with the actual stimulation patterns used in the ERGYS system. The ERGYS

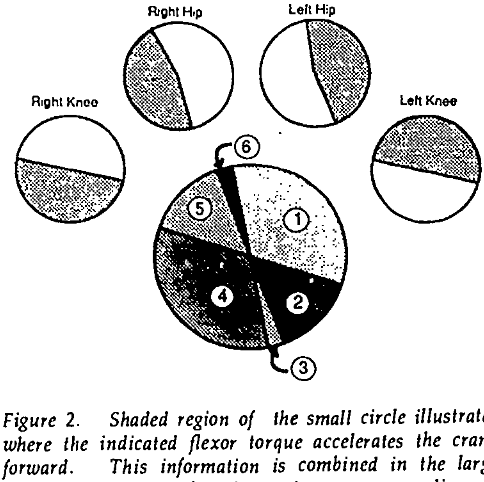


*Figure 2. Shaded region of the small circle illustrates where the indicated flexor torque accelerates the crank forward. This information is combined in the large circle to indicate the six regions corresponding to different combinations of right and left, hip and knee torques which will accelerate the crank forward. These combinations are: 1) Right knee extensor (RKE), left knee flexor (LKF), right hip extensor (RHE) ,and left hip flexor (LHF). 2) RKF, LKE, RHE, and LHF. 3) RKF, LKE, RHE, and LHE. 4) RKF, LKE, RHF, and LHE. 5) RKE, LKF, RHF and LHE. 6) RKE, LKF, RHE and LHE. Assumed linkage lengths are lth = 0.525m, lsh = 0 465m, lcr = 0.16m, lp = 0.6m, Θ = 25°.*

stimulation patterns are seen to be primarily aligned with the range of crank angles where the corresponding muscles are predicted to accelerate the crank forward. These results indicate, however, that it may be possible to achieve increased positive acceleration by increasing the range of crank angles where stimulation is applied. Also, although the ERGYS stimulation patterns vary with crank velocity, at any given velocity the crank angles where muscles are stimulated do not vary. They are the same for all physical configurations. However, the theoretical considerations of the accelerations that are produced by the stimulated muscles indicate that the function of the muscles is not the same for all configurations or individuals. Thus it may be possible to achieve improved performance from FES leg cycling ergometers by taking into account these differences, either by individualizing the stimulation patterns or choosing the geometric configuration to optimize the use of the existing patterns.

Acknowledgements

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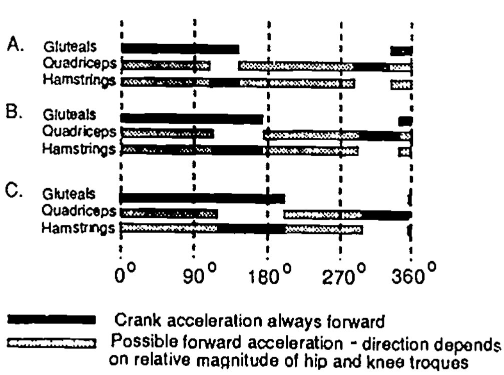


*Figure 3. Comparison of function of right gluteal, quadriceps and hamstrings muscle groups in different geometric conditions. A. The horizontal position of the seat relative to the crank center is 90% full leg extension. B. 70%. C. 50% . 0 degrees is at the top of the crank cycle for the right leg.*

Appendix

The crank angles corresponding to each singularity can be calculated by considering the geometry of the linkage. If the angle that the fixed segment between the hip and the crank center makes with the horizontal is known as $\Theta$, then singular positions for a knee torque, relative to the top of the crank cycle are $\Theta + \pi/2$ and $\Theta + 3\pi/2$. Also, the positions where the shank and the crank are collinear, and the acceleration due to a hip torque is singular are given by:

$$\sin(q_{cr} - \theta) = \frac{l_{th}^2 - l_p^2 - (l_{cr} - l_{sh})^2}{2l_p(l_{cr} - l_{sh})}$$

$$\cos(q_{cr} - \theta) = -(1 - \sin^2(q_{cr} - \theta))^{1/2}$$

or

$$\sin(q_{cr} - \theta) = \frac{l_{th}^2 - l_p^2 - (l_{cr} + l_{sh})^2}{2l_p(l_{cr} + l_{sh})}$$

$$\cos(q_{cr} - \theta) = (1 - \sin^2(q_{cr} - \theta))^{1/2}$$

Where $q_{cr}$ is the crank angle of the singularity position, $l_{th}$ is length of the thigh segment, $l_{sh}$, the length of the shank, $l_{cr}$ the length of the crank and $l_p$, the distance from the crank center to the hip center.

Lisa M. Schutte
Terman 552
Design Division, Mechanical Engineering
Stanford University
Stanford, CA 94305-4021

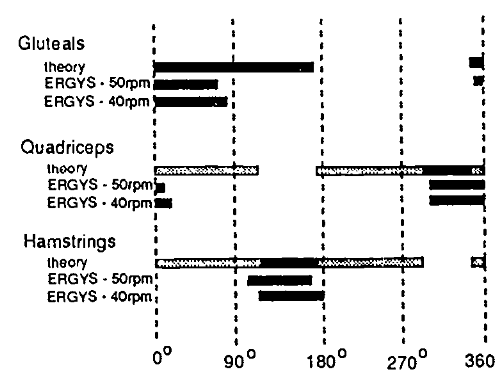


*Figure 4. Comparison of predicted crank positions where the muscle groups accelerate the crank forward (results are from Figure 3B) with the actual stimulation patterns measured in the ERGYS at 40 and 50 rpm. 0 degrees is at the top of the crank cycle for the right leg.*

# RURAL RESOURCES: ONE OF THE CORNERSTONES OF AGRABILITY

Tammy M. Schaefer and Andrea L. Speth
Resource Center for Farmers With Disabilities
Easter Seal Society of Wisconsin, Inc.
Madison, WI

## Abstract

Providing assistance to agricultural workers with disabilities or illnesses is at least four dimensional; 1) evaluation of the environment, equipment, individual; 2) provision of technical information; 3) connecting with appropriate service systems; and 4) preventing secondary injury or injury reoccurrence. For the purposes of this paper, focus will be on the third item.

Often the most difficult component of rural service delivery is connecting clients with relevant services. The issue is further complicated by elements unique to rural locales. Rural residents often have fewer resources available and agricultural workers are traditionally reluctant to seek out and ask for assistance. Developing a directory of resource services and people can become a valuable tool in helping clients get needed services.

## Background

In 1990, the United States Department of Agriculture appropriated funds to help establish programs to aid farmers or ranchers with disabilities or illnesses. These programs are now known as AgrAbility projects.

Many factors led to the decision to provide funds to aid agricultural workers with disabilities one of which was the concern that farmers often faced the problem of isolation from services which could be of assistance.

In the Wisconsin project, many calls were received requesting assistance in working with systems such as SSDI, local community aid programs, or the state vocational rehabilitation agency. Callers expressed anxiety about not knowing how or where to look for various sources of assistance.

## Statement of Problem

Because they are often located in isolated areas far removed from urban resources, many agricultural workers fall through the cracks of our nation's service delivery system. Despite the existence of agencies which could be a potential source of assistance, many of them are not explored or utilized by those who could benefit most from the services offered.

## Approach

In Wisconsin a concerted effort has been made to identify informational resources for clients. While there are many ways to obtain this information, the following methods have proven helpful.

**Resource Library**
Identify, research, and collect literature on local, state, and federal resources. Most agencies will provide brochures and pamphlets describing available services. Don't overlook everyday sources of information. Agricultural newspapers and magazines often include information on service organizations specifically designed to meet the needs of rural residents.

**Networking**
Utilize other professional's knowledge of available resources. Contact local human service departments for names of people who work with key programs. Contact individuals who offer similar services in other states, but be aware that states differ in the types of services available.

Don't overlook obvious sources. Past clients can be ideal informational resources. Based on their own experience, they can offer you information on individual agencies. Clients are usually willing to tell you why they were denied services. This may help you to assist other clients who need the same services. Encourage clients to become active participants in the networking process. This will not only give them a feeling of control, it will also free you to assist more people.

Remember to let resources you will be utilizing know that you will be using their services. Ask for the name of a contact person and provide that person information regarding the services your program provides.

**Question**
Don't be afraid to ask questions. No question is too trivial if it provides you information that you did not previously have. Some agencies i.e, the Social Security Administration, are so complex that few service providers can ever master all the aspects. Therefore, asking the right question may be essential to utilizing the agency to its fullest potential.

**Implications**

This approach to gathering information will net many important benefits for rural service programs. Perhaps the most important result is that you will be better prepared to fulfill most requests for information or at least provide a place to begin.

**Discussion**

Following these suggestions may help you spend less time searching for answers. You will have information readily available to offer clients, requiring less of your time on follow-through. Once clients are given the appropriate contacts, they will be able to follow through with less assistance from you.

Finally, it is impossible to be all things to all people. In order to be as effective as possible, human service organizations need to know, understand, and use resources that are available. In addition, organizations which serve rural residents must have a special commitment to providing client access to appropriate resource information.

**Acknowledgement**

This material is based, in part, on activities carried out under the AgrAbility of Wisconsin Program, a joint effort of the Easter Seal Society of Wisconsin's Resource Center For Farmers with Disabilities and the Wisconsin Extension Service. The AgrAbility of Wisconsin Program is supported by a grant from the USDA Extension Service.

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Tammy Schaefer
Resource Center for Farmers With Disabilities (RCFD)
Easter Seal Society of Wisconsin
101 Nob Hill Road, Suite 301
Madison, WI 53713

# Improving Culturally Appropriate Access: Finding a Middle Way

Alexandra Enders
Rural Institute on Disabilities
The University of Montana
Missoula, Montana

## Introduction

Information is the medium for communication of ideas. To improve equitable access to disability-related information and resources, the cultural context of information exchange needs to be considered. Cultural context is not just something to be aware of during international exchanges, it is a part of all human transactions.

## A Scenario for Misunderstanding

*They want the best and most recent state-of-the-art technology. No one can pay for it, training to effectively use it is out of reach, maintenance and repair will be a logistical nightmare, and it doesn't fit the intended environment.* Does the requestor live in an underdeveloped country, a major city in a developing country, an inner city in industrialized U.S., or rural America?

The differences may not be as large as one would initially assume. There are striking similarities, much of it in the way information is presented and how issues of cross-cultural communication are approached. Assumptions about perceived value of available options must be clearly understood by all parties involved. You can provide information and access to resources that seem to appropriately meet the identified needs. However if it is not presented in a format/context that the recipient values and trusts, it won't be an acceptable solution.

## Striving Toward Valued Outcomes

We are in the business of increasing the impact and acceptability of effective strategies, products, research findings, technical assistance, and training opportunities in the lives of people with disabilities. The outcome measures of our services and products should be based on the consumer's perception that something of value was received in the transaction. It doesn't make any difference that you see value in your intervention, if the individual or family you are working with finds it unacceptable, worthless, or inappropriate to his/her life, it is.

## Moving Away from a Black and White World

Not many years ago, a simpler world view sufficed. Countries were either industrialized or underdeveloped, technology was either high tech state of the art or appropriately low tech, societies were either bountiful rich "haves" or poor handout-seeking "have nots". U.S. health care scoffed at the rationed health care systems in some socialized welfare systems, insisting all Americans had equal access to state of the art medicine, and our domestic horror stories rarely surfaced.

Things have changed. Old categories don't work. We need better ways to distribute available resources. With the socio-political changes underway in the world today it is at best naive to view the planet as composed of industrialized haves and underdeveloped have nots. For example, the U.S. is now the world's largest debtor nation, and the highly industrialized eastern bloc countries are far from resource rich.

This is reflected in rehabilitation/disability services, where we need models that present solutions in categories that fall in-between the extremes of the high tech rehabilitation centers or WHO's community based rehabilitation scheme. Neither of these ends of the spectrum approaches work very effectively in rural America. Professionals in specialized urban rehabilitation centers frequently counsel their rural patients to remain in the city after rehab, because they are convinced that the necessary resources and supportive services will not be available if the person returns to their rural community. These cross-cultural biases (urban-rural) and unquestioned assumptions exist even if everyone involved is a WASP, and are only compounded by ethnic and socio-economic differences. Diversity, the buzzword of the 90's, assumes an acceptance of different cultural experiences -- cultural, ethnic, socio-economic. There is little acknowledgement of diversity in rehabilitation today, in the US or elsewhere.

## What Should We Call the Middle?

A curious vacuum exists for effective strategies that are in the middle of the spectrum. Most of the words that fit already have other connotations. Intermediate and appropriate are distinctly tied to international development efforts. Appropriate technology is generally focused on the needs of rural people in third world countries. When this approach is adopted by an industrialized country such as the United States, its target is usually the development and implementation of technologies appropriate for low-income communities, especially those in rural areas. Appropriate technology is grounded in cultural, political, and ecological frameworks; its proponents often share an almost evangelical zeal. Unfortunately most professionals working at the sophisticated urban end of the spectrum have little appreciation for this approach. It also tends to be rejected by urbanites in major cities in underdeveloped and developing countries.

The U.S. National Center for Appropriate Technology (NCAT) stated that "The main goal of appropriate technology is to enhance the self-reliance of people at a local level." If we substituted the word "assistive" for "appropriate", we would have a useful mission statement for many individuals working in our field. Appropriate assistive technology doesn't have to mean cardboard seats and tire tread sandals. We need a way of using the concepts implicit in appropriate technology, and presenting them in a format that even the high techies can find acceptable and valuable.

### A Closer Look From a Distance

International experience provides the outsider with a clearer view of his/her own culture, and the hidden assumptions that often lead to misunderstanding and miscommunication. It can also point to directions for developing new strategies

Working in Armenia, when it was still part of the Soviet Union, made me more aware of the need for a "middle way" to approaching cross-cultural communication related to services for people with disabilities. I have always been able to transcend the high tech/low tech gap. I've always been involved at both ends of the spectrum - the high tech environment of Stanford and the Electronic Industries Foundation, and the low tech world of DIY (do it yourself), scrounging for low cost solutions, and supporting projects in third world countries.

### Uncovering Hidden Assumptions

More than one of the patients on the spinal cord injury rehabilitation unit in Armenia could have benefitted from independent mobility while their pressure sores were healing. There were few gurneys available, and none could be spared to be fitted with drive wheels. Hesperian Foundation's Disabled Village Children has a clever adaptation for turning a wheelchair into a self-propelled prone trolley. The orthotist was able to build the adaptation, and attach it to one of the heavy, fixed-armrest wheelchairs. The first patient was shown the pictures of how the device could be used (you essentially drive the wheelchair backwards). Compliantly he agreed to try it, but then refused to leave his room in it. After repeated discussions (all through an interpreter), it was finally clear that he felt he had been given a peasant device, and though he liked the freedom, he was embarrassed by the image he felt it portrayed. He stated that though he came from a mountain village, he was not a peasant. He refused to use the mobility device on the Unit. Several weeks later, I found a project plan for an almost identical device in the appendices to Ford and Duckworth's Physical Management for the Quadriplegic Patient. The book had been circulating on the Unit, the pictures in the chapter on sexuality the major attraction. When the pictures of the similarly adapted wheelchair from the specialized rehab book were shown to another patient who needed one, he was eager to try it. The original device was adjusted to fit. When presented with the adapted chair, he refused, stating it was the peasant device that we'd used with the other individual. I remain convinced that if I had presented the device to the initial patient as originating from the sophisticated Ford and Duckworth text, and not with pictures of barefoot peasants, that the acceptance would have been completely different.

Coming from a subset of American culture that will accept just about anything that works, it was amazing to me to see a useful device rejected because of the image it conveyed. The more I observed, the more I could understand why some things were accepted, while others were rejected out of hand. Much of the causality lie in the way the information, service, treatment, or product was presented.

This was nor peculiar to Armenian mores. I worked as part of a multinational team; with members from 15 countries. When I tried to introduce material from the World Health Organization's community based rehabilitation (CBR) manuals, I found no support. Other's including the team leader from England and head nurse from Australia, felt these manuals inappropriate. After all, "we weren't in Africa". Having learned my lesson about using pictures, I assured them we would not use the pictures. The information in the manuals was directly applicable to helping develop a support system for use in the communities these individuals were returning to. Most of my colleagues could not get beyond the presentation style and format.

I returned to the U.S. convinced that we needed to find better communication vehicles, that we were losing valuable information because its developers did not see the broader market possibilities, and only packaged their data for a particular audience.

### Collaborating on a Middle Way

Today I see a broader audience than the two primary ones described. There has to be a middle way. Consider all the people who need the same basic content in the information developed for resource poor societies. A large number of these individuals are not and do not consider themselves peasants. The list includes the entirety of the former Soviet Union, the old eastern bloc countries, major cities in developing countries.

Much of rural U.S. could be considered in this category. People in many rural areas experience a curious blend of resource availability. They may have all kinds of high tech machines available to them during inpatient treatment: continuous passive motion, electrical stimulators, biofeedback devices. But if they need ongoing assistive technologies, they are probably going to be left to their own devices. Most Americans probably would not balk at building something that came from a book intended for third world citizens. But for most people this material would be difficult to locate. And sometimes it takes a little imagination to translate it. For example, a book from India has construction ideas for a low cart useful inside village huts, where most people cook and eat close to the ground. The same idea appears useful for a Native American dwelling which has a high doorway thresholds which are unrampable as part of the cultures spiritual belief system. The Indian trolley has a set of wheels that allow the driver to tip back and forth over a threshold. Someone needs to take the Indian material and redraw it so it is more available and graphically acceptable to Native American applications.

## Rural Challenge

The interpretive function is especially relevant for people living and working in rural areas. The first challenge is to collect the abundant folk wisdom of rural americans with disabilities. Then to make the information available to other rural people. Breaking New Ground has done a great job of collecting and synthesizing information. The next challenge is identifying other markets for this valuable rural information, and packaging the information so it can be acceptable to the cosmopolitan urbanite, internationally to people in developing countries, and to people who need a "middle way". An additional challenge lies in identifying relevant information that is couched in high tech, data laden research, and translating it so rural constituents (and everyone else) can understand and make use of it.

## Characteristics of a Middle Way

Middle Way projects and communication methods incorporate:
- realistic economic and cultural context
- accurate understanding of cultural self-perception (i.e. the way people see themselves and want their neighbors in the world to see them)
- flexibility and the ability to see beyond the boundaries of one's own cultural interpretations
- mechanisms for mutual two-way exchanges
- emphasis on the value of contributions by all participants, including explicit identification of what the outsiders will learn and receive in exchange for what they bring to the project
- full participation and equitable sharing among all participants, not a charitable giving to needy folks
- sustainability and self-sufficiency

Middle Way information sharing methods and materials:
- support individual dignity and initiative
- support system/infrastructure dignity, integrity, and initiative
- identify and structure ways to enhance productivity of all participants
- are active tools developed locally, not passive gifts accepted from outsiders
- encourage participants not recipients
- do not build cycles of dependency

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Alexandra Enders
Rural Institute on Disabilities
The University of Montana, 52 Corbin Hall
Missoula, Montana 59812

14.3

# THE RICKSHAW BUSHCHAIR

Ann L. Land Seating and Equipment Assessment Team
Department of Health and Community Services,
Northern Territory Australia

A project to develop a wheelchair for use over rough terrain has resulted in the designing and development of a manual transporter for the frail and disabled living in remote communities in northern Australia. The function of this mobility device is based on a rickshaw style chair of which there are two versions currently being tested. The design and the results of the trials so far are discussed.

## Background

Interviews with Aboriginal Health Workers and disabled people were conducted by the Rural Team Physiotherapist and Occupational Therapist. It became apparent that no commercial wheelchair met the needs of the disabled and their caregivers. An analysis revealed that:
1) the front casters of a standard wheelchair often caused the immobilisation of the user because they jammed or sank in sand. The casters were to be eliminated.
2) the ease of transfer from chair to vehicle and of standing to walk required the seat to be easily accessible.
3) the majority of wheelchair users were pushed from place to place instead of self propulsion. This was considered to be the main method of transportation. It was decided the easiest way to move the chair over rough ground was for the caregivers to pull rather than push. A pulling handle was designed. Shah (1990) reported similar observations in rural India

## Design and Development

In 1990,12 prototypes (8 convertible wheelchairs and 4 rickshaws) were tested (Land 1989). The Convertible Wheelchair was designed to be propelled by the user indoors and pulled by the caregivers outdoors. It was reported that this chair was not used indoors for three main reasons-1) the space was too limited inside the house,2) the users walked with assistance or pulled themselves along on the floor,3) people preferred to sit on the floor which is their habit. This concept was, therefore, abandoned.
The rickshaw was more readily accepted and compatible with the rural lifestyle therefore, in 1991, they were re-designed to meet the following criteria.
1) Stability: The location of the centre of gravity to be variable to accommodate a range of user body size, weight, height, shape and change in position from a static upright to a reclining moveable one when pulled along. To achieve this, the wheel configuration is changeable by positioning the axle forward or backward along the horizontal support of the undercarriage. Lateral stability is jeopardised when the user is transported over uneven ground therefore the wheel base can be widened by adjusting the wheels out further.
2) Safety: To prevent the chair from tipping over backwards anti-tip supports are situated behind the rear tyres. If the assistant loses control or releases the handle accidentally while pulling, the chair will balance in a tipped back position. A seat belt comes attached to the seat.
3) Ease of handling: A front support bar or a single microcellular large caster clears the ground when the chair tips back for pulling. This avoids getting stuck in sand or mud. Several different types of rear tyres are being used-2" wide BMX-24" trailer and wheelbarrow. So far, the latter has handled best. The pull handle of which there are the two styles allow more than one person to move the user and there is also a push handle at the back so the chair can be pushed and pulled at the same time.

4) Access for transfers: The seat is height adjustable to suit individual users. The footrest and the handle are moved out of the way for access and re-located once the user is seated.
5) Comfort: A hammock or a slung wheelchair style seat are the choice. Both styles have a high back to support the head in a tipped back position. Mesh/canvas/vinyl are materials being tested for durability and coolness . The footrests are of the same material and slung between two supports. Using a soft rather than a hard surface is best for bare feet as it prevent bruising and burning.
6) Durability: A sturdy construction with few moving components and few removable parts cuts down on costs for replacement of parts. The design is simple and maintenance can be carried out by a low skilled community mechanic.
7) Hygiene: The chair can be hosed down and the seat washed with detergent. The seat material can be replaced easily in situ.
8) Low cost: The Rickshaw is less expensive than a standard wheelchair in Australia.

As a result of the designing requirements two styles of the Rickshaw Bushchair were constructed. One is the hammock seat slung on a PVC frame which is reinforced with steel tubing. The handle is one piece and hinges to swing out of the way for user access to the seat (refer to fig.1). The second one is a wheelchair style seat slung on a tubular steel frame. The pull handle is telescopic, stores under the seat and is retractable (refer to fig. 2). Both chairs have wide tyres, a slung swing away footrest and anti-tip supports.

Evaluation

Two elderly female clients, one with Parkinsons Disease and the other with Left Hemiparesis, are using a chair each under supervision. An evaluation form for the caregivers and therapist to report their observation, a mechanics report and a video interview of the user are to be completed at the end of three months trial. It is expected that another prototype will be redesigned following the results.

Discussion

Although the prototypes have not been fully tested there are indications that both devices have design features which could be monopolised. For example, the hinged pull handle appears more successful than the telescopic handle because it is less complicated to use and more accessible. In answer to Zollars (1990) conclusive remark related to the use of PVC, the need to reinforce this material with steel tubing due to its poor strength defeated the purpose of keeping the framework lightweight. So far, our experience shows that PVC is not a viable material.

Conclusion

It is envisaged that the trials for the Rickshaw Bushchair will be completed by mid 1992 and a Final Report available towards the end of that year. A commercial enterprise will be sought for the manufacturing of this product in Australia.

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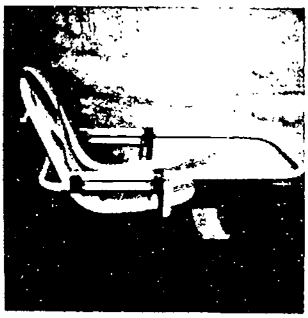

Fig. 1

Fig 2

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Ann Land
Co-ordinator
Seating and Equipment
Assessment Team (SEAT)
PO Box 41326
DARWIN NT 0811
AUSTRALIA

# MEASURING SYSTEM FOR ASSESSMENT OF TRAIL ACCESSIBILITY

Deborah J. Chelini & Peter W. Axelson
Beneficial Designs, Inc.
Santa Cruz, CA

ABSTRACT
The greatest single contribution toward the accessibility of outdoor environments and recreation areas is to document the degree to which existing recreational facilities are already "accessible." The development and implementation of a system for assessing, documenting and marketing information that communicates the "degree of accessibility" of outdoor trails has been initiated. Recreational opportunities exist which are already accessible by nature. Our hypothesis is: If people have access to information that documents the "degree of difficulty" of trails, they can decide where to hike and they can enjoy the experience.

## BACKGROUND

In recent years a perceived conflict between two major social movements has arisen--the movement to preserve our national wilderness areas and the movement to provide equal access and opportunity for people with disabilities. Wilderness values need not be compromised by special provisions of access for people with disabilities. The National Park Service recommends in a set of documents addressing accessibility that "persons with disabilities will, to the highest degree feasible and possible, be provided access to existing facilities and programs. Although maximum accessibility is the goal, this may not be physically possible in all cases, such as in wilderness areas."[1]

It is important to remember that every person has different functional abilities. The choice of an appropriate trail will be different for each person whether or not that person has a "disability." The purpose of this project is to collect data about trails that can be used to make decisions about which trails will provide an appropriate or desired degree of challenge and recreation for people with and without "disabilities."

The most intrusive developmental influence of this project would be recommendations for removal of specific barriers such as rock slide debris from what would otherwise be an accessible trail. Almost all trail maps have some general information about degree of difficulty, quality and natural history. Of several trails and park guides researched, a mountain bike trail book provided information most applicable to wheelchair accessibility. Visually presented information on gradation, text information on trail surface, general character description, and weather information were all presented in Roads to Ride South, A Bicyclist's Topographic Guide to San Mateo, Santa Clara and Santa Cruz Counties.[2] With the addition of side slope and trail width information, the guide would be a sufficient information source for a wheelchair rider needing to make a decision about hiking a specific trail.

## OBJECTIVE

A system of measuring those factors which influence the "accessibility" of a trail has been developed and applied in a pilot project. Three trails were evaluated, and data was translated into narrative and graphic forms. The objective is to develop a system wherein the trails assessment system can be taught at central locations to accessibility coordinators around the country. Data collected by these satellite coordinators would be sent to a central location for translation into maps and guides.

The purpose of the trail access measurement project is to provide information about the degree of accessibility of trails so that people with mobility considerations may judge whether or not, or how far, to proceed on a particular trail.

**METHODS/APPROACH**

It is important to have an initial meeting with the property owners or caretakers. At that meeting the purpose of the trail assessment is presented. Trails are selected for measurement; also maps and any written materials on the selected trails are obtained.

Preparation

A team is assembled that includes at least one wheelchair rider, a representative of the park or property, a person with basic orienteering or surveying skills, and other people who can assist and take measurements. The tools needed for measurement are a compass, a clinometer, an inclinometer attached to a four foot straight edge, a measuring tape, a large diameter rolo-tape, data collection forms, marking paint and flags, a notebook and a camera. The measuring process is practiced by the assessment coordinator and the team member who will make the compass and inclinometer readings. There are enough specific tasks to keep seven or eight people busy. More people will allow others to take breaks. A minimum team would be four people. Enough data forms are copied to cover sixty to eighty data points per mile. The weatner forecast is checked,, and food, water, sun protection and other personal items are assembled.

Measurement Process

Measurement tasks are assigned to team members, and an orientation of the process is presented by the assessment coordinator. The trailhead is marked with a sign which reads:

> **A** survey crew is measuring this trail for accessibility, please avoid scraping the dots from the dirt.

The first mark is placed at the beginning of the trail along with the sign. The distance from the initial point to the next point up the trail is measured with a rolo-tape. If there is no significant change in direction or slope, the measurement distance can be 100 feet; otherwise the measurement distance must be every fifty feet. The maximum side slope right and left is measured in degrees. Compass readings are taken at each point by sighting on an individual standing over the next measurement point. Inclinometer readings are recorded in percentage of slope; a plus indicates a slope up and a minus indicates a slope down. Trail width is noted wherever the trail becomes narrower than five feet. The individual recording the data sets up a sequence of receiving measurements from each individual in a logical process. The data recorder is also responsible for noting surface characteristics. It is a great idea to have one member of the team recording the event with a camera for documentation and to be able to give the volunteers copies of photos with an appreciation certificate.

Post Hiking Issues

The data is entered into a computer aided design program, and a map is generated. That map is coded to relate slope, surface, width and incline. A narrative description of the trail is also written.

**RESULTS**

**Measurement of Mt. Washburn Trail at Yellowstone National Park**

One of the trails measured in our pilot project was the Mt. Washburn Trail which is marked as "moderately difficult" at the trailhead. The trail has a steady, steep rise which, combined with the altitude, challenges endurance and strength. The trail is an old road with a clear width of eight to ten feet most of the way. Wherever the width of the road was impinged upon by large rocks or overgrown with vegetation, the remaining clear width was measured. The trail began as a dirt road with loose rocks of two to three inches in diameter. Changes in the quality of the trail were noted. Other surfaces encountered were larger loose rocks, rocks imbedded in the surface, cracked asphalt (vestiges of the old road), and gravel.

The hike up took five and a half hours, and the hike down took two. Measurements were taken at 100-foot intervals along most of the route. The first thirty points were slow and clumsy as everyone became accustomed to the rhythm of the data collection process and became familiar with reading their instruments. The process sped up so that each point took less than sixty seconds to measure and record. There were 220 readings for the Mt. Washburn Trail. The expedition was photographed and notes of Ranger Sue Consolo-Murphey's comments on the landscape and natural history were taken. A brief narrative giving specific information about the nature and location of rough spots and landings was written, as well as a description of the area's natural history.

DISCUSSION

The measurement, documentation and dissemination of objective information on trails is perhaps the greatest step that parks and recreation areas can take to make their facilities usable by persons with disabilities.

**WHERE WE GO FROM HERE**

There are two primary objectives to pursue at this point:

1.0 A centralized system for translation of the data into standardized maps with text needs to be designed, tested and implemented;

2.0 Trail assessment coordinators need to be trained.

Funding is being sought to implement these activities.

**ACKNOWLEDGEMENTS**

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Deborah Chelini
5858 Empire Grade
Santa Cruz, CA 95060

14.5

# A VIDEO GAME TO PROMOTE AEROBIC ACTIVITY FOR THE DISABLED

Bobby H. Chung
V.A. Rehabilitation Research and Development Center
Decatur, Georgia

## ABSTRACT

The purpose of SAAV is to help disabled persons improve their fitness levels. SAAV is a two-person interactive video game primarily controlled by the players' heart rate. The unique concept is to use a common denominator in every individual, heart rate, as a means of balancing unequal physical abilities while maintaining a level of exertion that promotes aerobic conditioning. SAAV is nondiscriminatory to people with handicaps, and it encourages the integration of the disabled and non-disabled populations.

## BACKGROUND

The importance of cardiovascular fitness for disabled individuals, especially paraplegics and other individuals who have lost the use of their lower extremities, is much greater than for able-bodied individuals because of their sedentary lifestyle. It is well documented that people who lead a sedentary lifestyle tend to go through a degenerative process characterized by decreased lean body mass, hypertension, reduced aerobic capacity, and increased risk of osteoporosis. It is imperative that a regular exercise program is encouraged.

Most amputees want to participate in leisure and sports activities which will help them lead a full and satisfying lifestyle. A full and satisfying lifestyle includes the ability to participate in avocational activities to improve physical fitness, sociability self-confidence, and to have fun.

## STATEMENT OF THE PROBLEM

In order for people to maintain a regular fitness program, there has to be motivation to begin and continue. The problem arises when motivation decreases due to inconvenience, the unpleasant atmosphere, and unequal levels of competiveness. Most motivational aids are designed only for one individual such as a *single* player video game or exercise programs broadcast on television or sold on video cassettes. This market is typically the home exerciser and very few maintain a regular exercise program because boredom usually sets.

The other alternative is joining a health club. The main advantage of using a health club is the built-in motivational atmosphere. Because everyone is exercising, one feels compelled to exercise. Generally, a health club is an excellent place where people can exercise under proper supervision while having fun. This is why health clubs can be so successful.

The primary reason why disabled people do not use health clubs is not because clubs are not accessible, (in most cases, only minor improvements have to be made) but instead, the equipment is not adapted to suit their needs. Placing stationary exercise machines especially designed for disabled people such as the Wheelchair Aerobic Fitness Trainer, in health clubs is one solution if it proves to be profitable. In order to increase profit, many disabled people must be attracted to the health clubs. Main attractions would be availability of a motivational atmosphere and the intergration of the non-disabled and disabled populations.

## APPROACH

The setup for SAAV includes an IBM compatible computer with VGA graphics connected to two wireless heart rate monitors, which in turn are connected to each of the players. Each player exercises on stationary aerobic machines designed for either disabled or non-disabled individuals such as arm ergometries, exercise bikes, or treadmills. The game begins when exercising starts and ends after a minimum of 20 minutes to promote aerobic training.

The object of the game is to collect the most points in a set time. A point is awarded for "eating" a "good" object represented by any nutritious food item such as an orange or broccoli. A point is deducted for eating a "bad" object labelled as either "fat" or "oil." As these objects "fly" across the screen at different heights, the player must use his/her magic carpet to intercept the object (figure 1). Control of the magic carpet is proportional to heart rate, i.e., the higher the heart rate, the higher the player

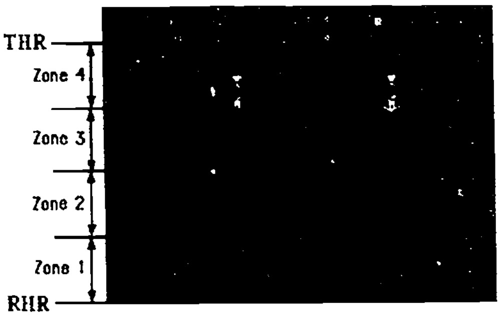


**Figure 1.** Game Screen - (a) Score bar (b) Time elapsed (c) "Bad" object (d) "Good" object

"floats upward." Since more of the desirable objects are flying higher across the screen, the higher the heart rate, the easier it is to earn points.

This menu-driven game begins with a "home" screen that gives the user the opportunity to change default settings, view a demonstration, or start the game. Once START is selected, the screen displays the player information sheet (figure 2). This sheet requires the player to

**Figure 2.** Menu-driven screen

provide information needed to determine the maximum heart rate (MHR) and to maintain a record of his/her past performances. The MHR is calculated by the conventional 220 minus age formula. The algorithm used to control the magic carpet is based on the target heart rate (THR) which is a percentage of the MHR. Because the THR increases linearly with intensity of work, each player chooses a THR based on the intensity of work he/she feels is most suitable. The choices range from very light (30% of MHR) to very heavy (85% of MHR). The screen is divided into four equal horizontal zones in which a player is allowed to float. Zone 1 begins at the bottom of the screen, and Zone 4 ends at the top of the screen (figure 1). Each zone corresponds to a *range*. A *range* is 1/4 of the difference between the THR and the resting heart rate (RHR) which is usually set at 80 bpm. A player must have a heart rate between the RHR and the RHR plus 1 *range* to float in Zone 1, a heart rate between the RHR plus 1 *range* and the RHR plus 2 *ranges* to float in Zone 2, and so on. Therefore, Zone 4 includes the THR and is called the THR zone. A player always floats to the top of a zone and hovers there until his/her heart rate qualifies for the next zone.

The incentive to remain in the THR zone is the greatest occurrence of "good" objects and least occurrence of the "bad" objects. Going above the THR zone, i.e., over-exertion, is unnecessary because one will already be in the highest zone.

For example, to see how the THR can eliminate physical advantages, suppose player 1 is a beginner, and player 2 is a well-conditioned athlete. Player 1 can set his THR at 60% of his MHR and player 2 can set her THR at 80%. Player 1 will not have to work as hard to be in the THR zone and will still be able to compete. In this way, the difference in athletic ability is minimized because the perceived intensity level is about the same.

To create a more competitive environment, three scoring schemes are used. The running point total of the two players will be shown on score bars appearing at the top of the screen, with the player's score represented by both the changing length and color (red, yellow, green) of the bar (figure 1). When the score bar is in the red region from collecting too many "bad" objects, the player's character will get "fatter" as he goes further into the red region. For every point deducted, a point is *added* to the opponent. When the score bar is in the yellow region, scoring is normal and does not affect the opponent's score. When the score bar is in the green region, every point scored results in a point being *deducted* from the opponent.

## IMPLICATIONS

SAAV is not just a motivational aid for the disabled, but a motivational aid for all people who believe that exercising should be enjoyable. For this reason, health clubs can use SAAV as an attraction for new members, and then profit from the additional memberships can be applied to offset some of the costs in purchasing the stationary exercise equipment for disabled people.

The goal is to have health clubs use SAAV with existing exercise equipment in conjunction with exercise equipment for disabled individuals so that they may have a convenient place to exercise.

## DISCUSSION

The advantages in using SAAV is two fold. First, SAAV takes advantage of the health club atmosphere and therefore provides an extra motivational aid to people for exercising. In addition, unlike most motivational aids, SAAV uses friendly competition from another individual to increase motivation to exercise. Second, monitoring heart rate is the healthy way of measuring aerobic fitness by giving direct feedback. SAAV keeps a record of previous sessions for instant recall of one's progress.

One of the main attractions of this game are that, regardless of the fitness level, unequal competition is virtually eliminated thus allowing friendly competition. In addition, because it only requires an IBM compatible computer and twc heart rate monitors, the low-cost investment is a means to integrate the disabled and non-disabled populations.

Future plans will include verifying this concept in a pilot study using subjects in a simulated health club environment.

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VA Rehabilitation R&D
1670 Clairmont Road (MS 153)
Decatur, GA 30033

# NATIONAL RURAL RESOURCE PROJECT

Reg J. Urbanowski, James W. Vargo
University of Alberta, Edmonton, Alberta

The National Rural Resource Project (NRRP) is a project of the Department of Occupational Therapy at the University of Alberta developed in 1991 as a result of needs expressed by rural consumers with disabilities. The mandate of NRRP is to assist rural Canadians with disabilities and their families lead full and productive lives through information and education, research, and networking.

National
Rural
Resource
Project

*Introduction*
Farm life has many unique facets which pose special challenges for farmers with disabilities and their families. These challenges may relate to the physical environment, work roles, family life, or personal adjustments to new situations. Farm life is distinctive in the demands it places on individuals in a family unit and on the family as a unit of production. How work is organized, how people relate to each other to get the work done, and how people get their individual needs met is a daily challenge. Sometimes work and family life must be re-ordered to meet the needs of the person with the physical disability, the family, and the farm firm as well. In these instances, families may require assistance in making the adjustments necessary for fulfilling and rewarding lives.

In 1987, Regina, Saskatchewan, hosted a national conference called "Shifting Gears" which focused on the needs of farmers with disabilities and their families. One of the primary concerns that emerged from this conference was the need for a national mechanism which could provide help and information to disabled farmers and their families. The first step in meeting this need was the formation of a committee under the auspices of the Canadian Paraplegic Association. That committee recommended the establishment of a centre whose mandate would be to provide rural Canadians with information regarding a wide variety of disability issues. Two years ago, the Department of Occupational Therapy at the University of Alberta undertook the task of establishing and housing such a resource centre. In 1991, DowElanco Canada provided funding for three years to the newly established National Rural Resource Project to begin operations. Since then, additional funds have been received from sources such as Agriculture Canada and the Alberta Paraplegic Foundation for specific projects conducted by the National Rural Resource Project.

*Philosophy and Goals*
The philosophy of the National Rural Resource Project (NRRP) is that rural Canadians dealing with disability can lead full and productive lives, given the appropriate resources. Many resources are available to help families cope with disability, but unfortunately, these resources are often inaccessible to people living in rural areas. Even when resources are accessible, many people are not aware of them. The goal of the NRRP is to inform and educate

rural Canadians on issues related to lifestyles and disability.

It was realized early on that there was a need to develop new and innovative ways to disseminate information to rural Canadians. The Department of Occupational Therapy struck a core team to operationalize the philosophy and provide direction for the project. The first task of the core team was to design parameters for the project that included accessibility and flexibility in responding to a variety of identified community needs. From a review of the literature, it was decided that this could best be accomplished through the use of cluster teams. The advantages of the cluster team approach include the following:

1. Each team is allowed to progress at its own pace
2. Each team is a self-sustaining unit, which means that there is no need for a hierarchy of supervision.
3. Each team is organized around a specific content theme and exists to achieve a specific purpose.
4. The human resource requirements for a cluster team approach are less than those for conventional methods.
5. The time commitments for volunteer team members is flexible according to the needs and availability of the team.
6. Administrative costs are minimal.

Through consultations within the Department and with persons with disabilities and their families it was recommended that NRRP engage in the following projects:

1. Develop informational brochures.
2. Investigate the impact of a parent's disability on psychological and social development of their children.
3. Prepare public service announcements.
4. Distribute currently available media productions.
5. Produce and distribute a national newsletter for farmers with disabilities and their families.
6. Write articles to be distributed through a network of rural newspapers.
7. Establish a network of professionals and consumers brought together by a common need.

*ACCESS*

Three dimensions related to access have been identified:

*1. Information.* Information related to disability and lifestyle must be easily accessible to rural Canadians. To achieve this, NRRP has developed linkages with organizations and agencies that have grassroots connections with the rural community, eg. - rural health units, organizations for disabled farmers, agricultural associations, and rural newspapers.

*2. Service.* NRRP does not provide direct client service. Instead, it serves as a catalyst whereby the consumer and provider can be brought together. In exceptional circumstances, such as where no service is available, NRRP may provide services depending on the nature of the need and the availability of resources.

*3. Collaborative projects.* NRRP is seeking to further develop partnerships in projects which lend themselves to our philosophy and operating principles. We are pleased with our progress to date, but would like to expand our collaborative efforts to include others currently not involved. The goal of this collaboration is to bridge the gap between professionals and rural consumers regardless of where they live and work.

*Future Directions*
Future directions of NRRP will focus on three areas: information and education, research, and networking. Specific projects planned for each of these areas are as follows:

1. *Information & Education*
   a. expand the pamphlet series in the three tracks of individual well-being, family life, and environmental modification. Two more are currently in progress: Asking for Help, and Safety in Equipment Modifications.
   b. develop and distribute a quarterly newsletter .
   c. establish partnerships with content experts who will contribute to our rural newspaper article series.
   d. develop and distribute informational materials using a wide variety of media sources: print, audiotapes, videotapes.
   e. to continue to present the philosophy, goals, and progress of NRRP at national and international meetings.

2. *Research*
   a. to foster research on the farm family and disability through liaison with community, service, professional, and educational organizations.
   b. to conduct basic research on the physical demands of farm work.
   c. to investigate the effect of parental disability on their children.
   d. to examine the most effective means of adapting the farm environment when conventional methods have failed.

3. *Networking*
   a. to continue to build an information dissemination network.
   b. to expand the base of rural consumers who could benefit from NRRP services.
   c. to develop and maintain a registry of content experts who could contribute to NRRP activities.
   d. to refine our mechanism for linking consumers with content experts.

Reg Urbanowski, MSc
Project Director
National Rural Resource Project
Department of Occupational Therapy
Faculty of Rehabilitation Medicine
University of Alberta
Room 3-45 Corbett Hall
Edmonton, Alberta
T5G 2G4

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# Introducing Seating Concepts in Rural Areas: A Model

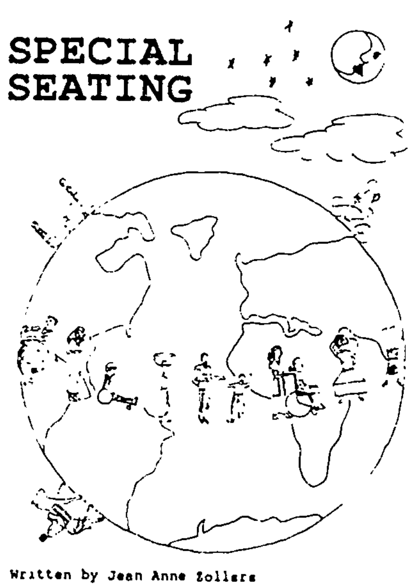
Jean Anne Zollars, PT and Jamie Noon, Seating Clinician
Rehabilitation Engineering Center
Lucile Salter Packard Children's Hospital at Stanford
Palo Alto, California USA

**Abstract**
A model for introducing seating concepts in rural areas was developed from the authors' experiences in rural Mexico. The instructional approach includes an illustrated *Special Seating* manual, a three-day instructional course, and a design for an inexpensive seating evaluation chair.

**Introduction**
This seating instructional model was inspired by two projects in Mexico where innovative seating is provided to children and adults. Project Projimo, in Ajoya, Mexico, is run by people with disabilities who evaluate individuals and provide appropriate therapy, wound management, technology, and vocational training. The instructional model is intended to expand the workers understanding of seating concepts and to stimulate the development of designs and materials to improve the effectiveness of their seating systems. This instructional model assumes that many people with disabilities in rural areas live far from rehabilitation centers, have little access to physical and occupational therapy, and rehabilitation technology suppliers. Often people cannot purchase commercially available wheelchairs and seating systems because of the high cost.

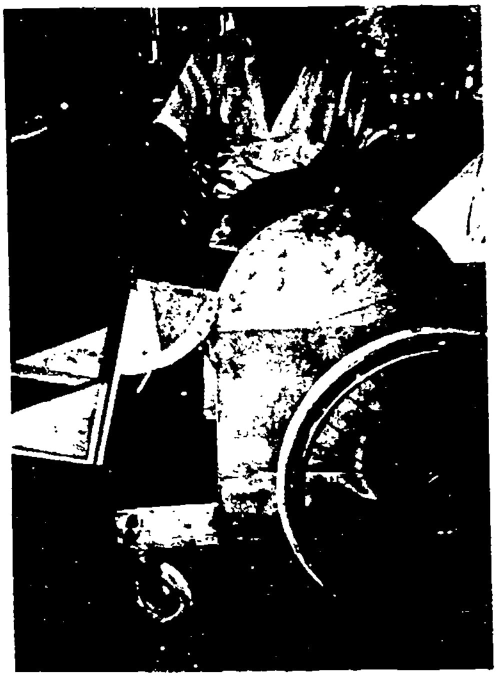
In June 1991, the authors and ten workers from Project Projimo designed and built a seating evaluation chair. A one day course was then taught which included the assessment of persons for special seating, an evaluation demonstration with a child, and fitting the evaluation chair to the child. Subsequent to this visit, an illustrated manual was written to guide people in seating assessment and the desin of seating systems for people with disabilities. Thus, the model we are introducing has three components: the *Special Seating* manual, an instructional course, and a design for an inexpensive seating evaluation chair

**Special Seating Manual and Course**
This 63 page manual is written for community health workers, parents, teachers, and anyone who is making a special seat or cushion for a person with a disability. The manual does not use medical or therapy terms which are often confusing. The manual is written with understandable language, and is fully illustrated for clarity and to assist people who do not read well. It first discusses the importance and goals of seating. Then it covers physical, functional, and postural assessment with a strong emphasis on hands-on evaluation. The course is designed to be taught in three eight-hour days. It follows the *Special Seating* manual, but includes slides and videotapes (if this technology is available); extensive hands-on practical work with each other and clients; use of the seating evaluation chair and/or "mocking-up" seating systems; and brainstorming about the design and fabrication of the devices. After the completion of the three day course, instructors of the course will work with the participants building seating systems for clients.



### Seating Evaluation Chair

It is important to take seating concepts out of theory and show concrete seating options. This can be accomplished by "mocking-up" seating systems and/or by using a seating evaluation chair. The workers at Project Projimo thought an evaluation chair would be helpful, so the authors conjointly with the workers designed and fabricated this device. Because the workers were involved in the chair's development, they were more motivated to use it than if the device had been given to them. The evaluation chair facilitates measuring seating dimensions and angles, instead of using confusing goniometers or measurement tools. The evaluation chair needed to be simple and inexpensive, made of readily available materials, and multi-adjustable to position people of varying sizes and disabilities. The original chair was constructed mostly of wood. It was adjustable in seat depth, seat to back angle, orientation in space, leg length, and knee angle. Adjustable positioning components such as lateral trunk supports, hip supports, medial and lateral thigh supports, head support, and anterior chest support were also used. The angle of the seat and back were achieved by using a common axis and telescoping tubing.



The hope is that the evaluation chair design will continue to evolve or perhaps remain somewhat undefined, such that each one is different and best suited for its particular location. Some new designs are being explored to meet changing design criteria. In addition to the original design criteria, new designs will be lightweight, portable and easier to make. One possible idea is a tubular frame which can be folded and carried like a backpack. Optimally, this system will fit into a standard wheelchair so that people can be evaluated for self propulsion.

### Conclusion

Offered here is a problem solving approach, a framework, not a definitive method for seating. If this approach is effective, local workers will be able to use this information as a foundation and create innovative seating systems according to their clients individual needs. It is important that ideas are shared and exchanged, rather than imposed. The community workers must be involved in every step of the learning and designing process, so that indeed they will continue the service after the instructors leave.

Please send design ideas or comments to:
Jean Anne Zollars, Jamie Noon
Rehabilitation Engineering Center
Lucile Salter Packard Children's Hospital at Stanford
725 Welch Road
Palo Alto, CA 94304
(415) 497-8171







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# A RESOURCE MANUAL OF AGRICULTURALLY RELATED ASSISTIVE TECHNOLOGIES FOR FARMERS AND REHABILITATION PROFESSIONALS

Dean A. Brusnighan
Breaking New Ground Resource Center
Purdue University, Agricultural Engineering Department
West Lafayette, IN U.S.A.

## ABSTRACT

Each day there are probably hundreds of new solutions created by farmers with disabilities to overcome problems that they commonly face. Examples range from castrating pigs using one hand to mounting and driving a tractor without the use of one's legs. In addition, producers with disabilities discover commercial products that save time or frustration when performing certain farm tasks. These commercial products and self-made solutions, which can be referred to as rural assistive technology, are a valuable resource that should be utilized both by other farmers and by rehabilitation professionals. A resource manual containing descriptions of a wide variety of rural assistive technologies applicable to a wide range of disabling conditions is described.

## BACKGROUND

An estimated 500,000 farmers, ranchers and agricultural workers in the United States are severely hindered in the completion of essential agricultural work tasks because of physical disabilities. These disabilities include not only the most obvious forms such as amputations and spinal cord injuries but also a wide variety of other disabling conditions such as low vision, hearing impairments, arthritis, chronic back pain, heart conditions, and respiratory impairments. Experience has shown that many of these individuals possess interest in and a desire to remain actively involved in their farm operations With proper worksite modifications and appropriate assistive technologies, most farmers with disabilities are able to work productively on their farms. However, difficulties sometimes impede an individual's return to work.

One problem lies in the farmer's inability to access information regarding the needed agricultural modifications or technologies. Farmers, ranchers, and agricultural workers with physical disabilities frequently lack access to ideas and solutions of others who have overcome similar worksite problems. In addition, no databases are currently available for agriculturally related technologies that would permit a farmer to search for existing solutions. There is a general lack of resources that allow farmers with disabilities to discover or examine potential solutions.

Another difficulty is the lack of experience many service providers have with agricultural enterprises and the associated equipment, tools, and structures. Thus, they may also lack information on which to base recommendations for rural assistive technology for their farm or ranch clients.

## OBJECTIVE

To assist both farmers and service providers, the Breaking New Ground Resource Center has developed and published a resource manual that helps readers identify existing solutions to common problems encountered when farming with a physical disability.

## APPROACH

Containing over 400 pages of solutions, photos, descriptions, and resources currently being used by agricultural producers with physical disabilities, *Agricultural Tools, Equipment, Machinery & Buildings for Farmers & Ranchers with Physical Disabilities, Volume 2* provides a single source for simple, effective solutions to many problems commonly encountered by these producers. Topics include: lifts and techniques for accessing agricultural equipment, control modifications, commercial accessories for agricultural equipment, modified tools and specialty equipment, agricultural building modifications and worksite accessibility, lifts and techniques for accessing automotive equipment, and recreation. Resources include: safety information, agricultural worksite assessment tools, technical reports of concern to producers with disabilities, and a rehabilitation technology bibliography.

Gathered from both individuals and commercial sources, each solution presented in Volume 2 lists the problem that the item described helps overcome, the name and address of the source of the solution, the cost when possible, and a full description of the solution with one or more photographs.

## DISCUSSION

Documentation of rural assistive technology in such a resource manual can provide a variety of benefits. These include: 1) an increased awareness that farmers with disabilities are capable of returning to farm work, 2) an opportunity to review the relative safety of a farmer-built solution, perhaps leading readers to avoid the same unsafe practices, and 3) a reduction in the amount of time invested by farmers to develop and build a rural assistive technology solution.

The most basic benefit is an increased awareness in both farmers and rehabilitation professionals that individuals with disabilities can continue to work productively in a farming operation. Rehabilitation professionals in urban centers, where agricultural workers are often sent after a disabling injury, are made aware that farming as an occupation can continue for the individual. A farm family viewing a collection of solutions from other farmers with disabilities in similar situations can receive encouragement that their situation is not unique. Volume 2 accomplishes this by providing concrete examples of farmers and ranchers who are cultivating their own independence by working on the farm in spite of a disability.

A compilation of rural assistive technology solutions also provides a setting to critically review designs for good or poor attention to safety so that readers can benefit from the comments made. By discussing the safe and potentially unsafe aspects of farmer-made solutions included in Volume 2, it is believed that readers can be influenced to incorporate some of the safety features discussed and/or to avoid unsafe aspects in any resulting solutions that they might build.

Providing descriptions and photos of existing solutions can reduce the amount of time a farmer spends designing, developing, and building a solution for his/her own use. A farmer can choose to use or adapt an idea that has already been built and proven to work in a similar setting. Reducing the time spent to design and build a solution results in a more rapid return to productive work.

The size and distribution of rural populations to be served dictate that rehabilitation professionals cannot currently provide all of the solutions. We must make use of the solutions which are already available from those who best understand their problems--farmers. Rural assistive technology, especially that created by farmers, is a valuable resource that should be taken advantage of.

You are strongly encouraged to send descriptions of rural assistive technologies to the author. The Breaking New Ground Resource Center continues to collect and compile these ideas to produce a forthcoming supplement to the Volume 2 resource manual. Only by sharing the solutions we all encounter can these rural assistive technologies be made accessible to the widest possible audience.

## ACKNOWLEDGMENTS

Funding for this project was provided by Deere and Company, Successful Farming Magazine, the National Institute on Disability and Rehabilitation Research (grant number H133A90004-90), and the Rehabilitation Services Administration (grant number H128A01027).

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Dean Brusnighan
Technology Specialist
Breaking New Ground Resource Center
Purdue University
1146 Agricultural Engineering Building
West Lafayette, IN 47907-1146 U.S.A
(317) 494-5954

# Design for Commercialization

Cabell C. Heyward, Riley Hawkins,
Alan Harp and Niki Elder

**Abstract**
One of the most frustrating dilemmas in the field of rehabilitation engineering is the unavailability of products and devices needed by persons with disability, despite the large numbers of custom built devices designed specifically for the use of an individual client. Many efforts on the part of designers and e[illegible]neers are unknowingly duplicated, efforts to commercialize products rarely meet with success, yet there are many indispensable and low cost commercial items purchased by the disabled population that were not even intended for the disabled market.

One solution may lie in the broadening of the applicability of the concept for the new device to include larger markets, the result being that disabled persons could take advantage of the greater likelihood of the product being mass-produced, and reduced purchase price and increased reliability once the device is in production.

## Problem Statement

The Center for Rehabilitation Technology is involved in a continuing partnership with the State of Georgia Division of Rehabilitation Services to develop assistive devices for state Clients seeking employment. This effort has resulted in the development of hundreds of new devices presently in use by state clients over the past ten years. Almost always, these devices are experimental and are unique to the client and his vocational needs.

One of the goals of the Center is the commercialization of devices that demonstrate merit to others besides the client for whom it was originally designed. A sister organization, Center for Rehabilitation Technology, Inc. employs marketing personnel to evaluate each new device and, where possible avail them to others through publishing, licensing, or, as in the case of the AbleOffice workstation system, producing it through local industry

•There are many similar efforts to CRT going on nationally, yet it is still apparent that products needed by individuals with disabilities are neither available nor affordable. There is a tendency in the rehabilitation engineering field for development efforts to be duplicated repeatedly as devices are custom built to suit the needs of only one client.

•There is the inherent difficulty in marketing products intended for use only by disabled persons. A small market means low production volume and high retail cost.

•There are many commercial products found to be very useful to persons with disabilities that are inexpensive and available, that were targeted towards other, much larger markets: remote appliance switching devices and alternative signaling devices for telephones sold by Radio Shack, speaker phones, electric staplers and letter openers, magnetic hammers, keyboard trays and etc.

## Approach

Recent projects at the Center have provided opportunities for the design of new devices where the design requirements were expanded to satisfy more than the requirements of the client at hand. If a device can be designed for broader application from the start, even to include segments of the able bodied population, then the ultimate availability of the device to the disabled population should improve.
These cases will illustrate:

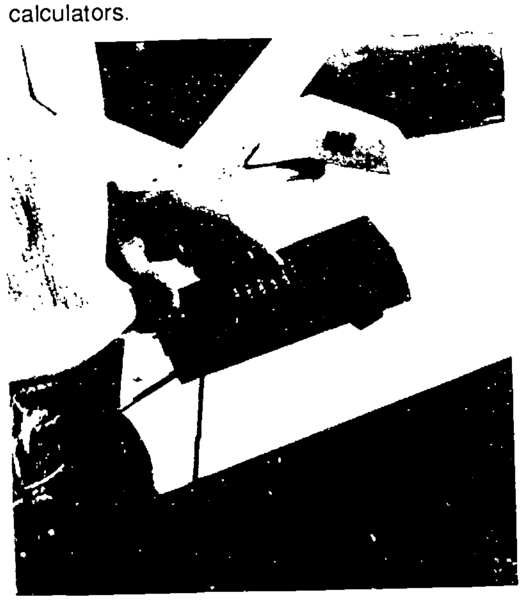
## Solutions:

1. The client is blind with cerebral palsy and works in a film development lab where the work surfaces are of varying heights. The client uses a wheelchair and must share the work environment with other employees. Elevating wheelchairs were dismissed as unaffordable. The furniture

could not be changed without undue cost and adverse effect on others also using the equipment.

A device designed to elevate the clients sitting height in her wheelchair was considered until it was realized a more broadly applicable solution was to design an office chair in which the seat height could be adjusted under power. A typical model was chosen; an Ergon ER210 by Herman Miller, and the pneumatic cylinder was substituted for a device using a gear driven power screw and a battery powered electric motor. The client has used the chair daily for nearly a year at the time of this writing. The client transfers from her wheelchair and propels herself short distances by pushing along the edge of the work surface. After three months of use, a repair and design modification was made, however, the chair has performed reliably since then. It is believed that there is a large able-bodied market for this device since there are many who take advantage of pneumatic cylinder chairs who cannot remove their weight from the seat in order to elevate.

2.This client is a one-arm amputee who works as an automotive damage claims adjuster. Rather than take notes, he enters information into a hand held "inventory computer". It is impractical to rest the unit on an available surface to press buttons, or to use his thumb while holding the unit with the four fingers. The solution in this case is a "shelf" onto which the unit is mounted, which is worn on the belt. The shelf is adjustable in angle and folds in a vertical orientation to function as a carrying case. It does not need to be removed during the course of a days work and provisions are made for it to be recharged and plugged into a processing computer while still mounted in the device. It is also useful to inventory clerks who need both hands free. It can be easily made to accept minor variations in size of inventory computers or calculators.



3.The client in this case has a spinal cord injury at the C4/C5 level. He was seeking employment as a telephone salesman with a major mail order catalog company. He was set up with computer equipment accessed by mouthstick to process orders, but was still required to memorize and refer to items in any of twenty nine catalogs and sales flyers. There were several commercially available items that would have provided access to the catalogs including components of the AbleOffice system. However, an additional performance requirement was decided upon: it should take no more than one minute or so to locate a catalog item. The solution takes the form of a catalog rack which slides from side to side under power. As the catalogs pass a central flipper bar, the catalogs are opened then closed in succession. Two momentary push buttons control the direction in which the rack travels. The largest catalogs are divided so the client never has more than 100 pages to turn by mouthstick. The speed at which the catalog rack operates means that it could be useful as a means of increasing efficiency for anyone working with reference books.

**Discussion**
In each case it was realized that a direction for design development could be chosen that would maximize the applicability of the final solution, rather than to only satisfy the requirements of the client. In no instance were the needs of the client compromised for the sake of the product. While no cost comparison is available, it is felt that the cost in terms of additional funds or time required was not significant in the examples mentioned.

Despite each client having received an untested prototypical device, as they would have, there is an advantage in that fewer development projects will be needed to advance the device to a pre-production stage, and to generate a complete set of working drawings in preparation for licensing or production. When a license is sought, the number of potential buyers will be greater, as they will for the device once in production.

**Acknowledgements**
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Cabell C Heyward, Project Coordinator
Center for Rehabilitation Technology
Georgia Institute of Technology
Atlanta, GA 30332-0156

# Computer/Office Ergonomics for Persons with Physical Disabilities

Jeff Symons
California Department of Rehabilitation

## Introduction

Before evaluating various computer access methods for persons with physical disabilities the ergonomic position of the person and equipment should be considered. Proper position of both user and equipment is essential to enable the user to access their environment with the least amount of strain on their body. When looking at the ergonomic position one must look at the entire person and environment because what affects one person or part of the body can often affects others. Care must be taken to not solve one problem while creating another one. If the equipment is positioned in such a way that makes it easier for the person to see a device but requires them reach in an awkward manner to access the device, this may not be the best solution.

Besides computer access most jobs require a variety of other tasks such as writing, filing and telephone work. In each of the tasks the ergonomic position of the person and devices should be assessed. In addition, environmental factors such as others who may have to use the same equipment or space must be addressed.

This paper will discuss the principles of ergonomic positioning of persons <u>without</u> physical disabilities and how the same principles can be applied to persons with physical disabilities.

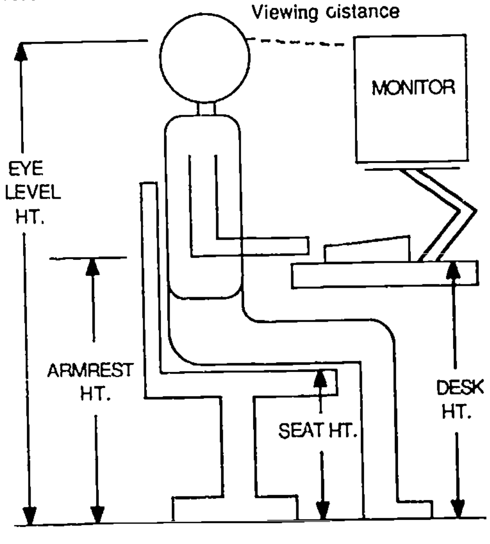
## Backround

Some general principles of ergonomics are:

- Try to keep the body in as anatomically neutral a posture as possible. Long term asymmetric postures can be detrimental.
- Muscles can perform their best when they are at or near the center of their range of motion. Repeated reaching and to perform a task can be detrimental.
- Listen to your body. If a task is causing pain or discomfort try to think about what could be causing this and how to change this position.
- Take frequent short breaks and change positions

The proper ergonomic position for a person sitting at a desk is (see figure 1); feet flat on the floor or footrest with the knees bent at no more than 90°. The thigh-to-torso angle should never be less that 90°, and preferably 110° to 145°. The head should be kept in near a neutral position as possible. The work height should be even with or slightly above the point of the elbows. Work height should not be confused with the desk height. The work height is the height from the floor to the object or equipment the person is working on. For example if the person is typing on a typewriter the work height would be measured from the floor to the home row keys. The desk height is 2"-3" lower than this. The work should be placed at a comfortable distance from the person. Each individuals best visual acuity distance is different, normal visual acuity is between 15"-25".

The appropriate ergonomic position depends on the individual as well as on the task. Computer work is generally done in an upright sitting posture, while reading and writing are generally done in a forward leaning posture. The proper chair and desk height for working on a computer will probably not be the ideal for reading or writing. There are several ways to achieve the optimum positioning of a person and the equipment they must access. For example, a height adjustable desk could be used for an individual that needs a lower desk, or a foot rest could be used with a standard higher desk.



### Equipment

Chair

There are many similarities between the proper ergonomic seating for an ergonomic office chair and for a wheelchair user. The seat of the chair should evenly support the thighs, while the feet should rest flat on the floor or footrest. There should be about 2-3 inches behind the back of the knee and the end of the chair. The chair should not be more than 2" wider than the person. The armrest should be slightly higher than the point of the elbow. Since most people will be performing a variety of tasks such as computer work, writing and reading that require different postures an ergonomic chair should be adjustable enough to accommodate the different postures. The seat must raise and lower as well as tilt back and forward to accommodate the different postures. The backrest should also be adjustable in height and tilt forward and back to fit the curvature of the user and their posture. Persons who have neck problems often prefer a backrest that also provides some neck support as well. Some ergonomic office chairs offer adjustable arm rest to enable the user to position the armrest at the proper height. Trying a chair for 5 or 10 minutes in a showroom is much different than using it at the work site. It is best, if possible, to get a loaner chair for a day for the user to evaluate.

Desks/Work surfaces

The standard desk is 28"-30" high which is approximately a good height for most individuals that are 5'8"-5'10" tall. The proper desk height is one where the work can be accessed with the elbows bent at 90° or slightly greater. There are 4 basic types of desks; the standard nonadjustable ones, those that can be set at a particular height when assembling, ones that can be adjusted by a crank and those that have power adjustable height feature. Some nonadjustable desks can be raised by putting leg extenders under the legs. However these only work if you need to raise the desk. Typically a person in a wheelchair seat height is higher than a person in a office chair, therefore the desk needs to be higher. If leg extenders are used to raise a work surface to the proper height for an individual, if others must use this same work surface their needs should also be addressed. A desk where the height can be set when assembling can be beneficial in situations where there is only one primary user of the desk and they need it a particular height that a standard desk will not work. In particular if the desk needs to be lower than a standard desk. The reason for the a crank adjustable desk might be if others had use the desk, or the user had to significantly change positions several times a day. The crank type desks are particularly useful in situations where there are multiple users with varying needs. A power adjustable height desk is useful when the user must change positions frequently. For example a person who can sit for only a short period of time and then needs to stand. A crank desk could be used but having to crank a desk up and down several times a day can be not only time consuming but stressful as well.

Computer Monitor and Keyboard

The neck and head should be kept in a neutral position. The top of the monitor should be at eye level. Frequently monitor arms are used to accomplish this. Monitor arms also enable the user to position the monitor the best distance away from them for their visual acuity. The keyboard should be positioned such that the wrist stay in a neutral position and not resting on sharp corners of a surface. Many keyboard drawers are available that enable the user to adjust the height and angle of the keyboard. In addition to the monitor and the keyboard, the position of the documents that the person is working from should be addressed. There are a wide variety of document holders that can be used to keep the neck in a neutral position. However when applying these principles to persons with disabilities the position of the equipment can change drastically. For example the case where the person accesses a keyboard with a mouthstick. In order to keep the head and neck in a neutral position the keyboard should be re-positioned. One possible position is mounting the keyboard tilted up vertically and just below the front of the monitor. There are desk that have the monitors mounted in them. While this can make it easier to see the screen and keyboard at the same time it can require the user's neck to be constantly flexed forward. Another example is for someone who has good gross motor control of there arms but lacks the fine motor control to strike individual keys a typing aid can be beneficial. Some typing aids require the wrist be rotated so the palms face down in order to use them while others allow the palms to face each other which can be less stressful than the palms down because not as much rotation is required.

Telephone

Often people who use the phone must also write at the same time. With a standard phone receiver a person often bends there neck to one side to hold the phone while they write. This can cause a lot of strain on the users neck. A phone shoulder rest can help this relieve the strain. A headset enables the user to keep a good ergonomic neck position and the hands are free to do other tasks. However, persons with limited range of motion and strength may not be able to independently don and doff a headset. There are new cordless headset which enable the user to move around untethered but a user may still need help to don and doff the headset. A speaker phone, while often used in home situations, is only sometimes used in office situations because of the lack of privacy. An example was a woman who had arthrogryposis and used a chin control for her wheelchair. She worked as a receptionist and used a mouthstick to access the phone but used an attendant to hold t phone. The various options were discuss . She wanted to be as independent as possible. While the cordless headset would make her independent around the office she would still need help to don and doff the headset. We discussed making a mounting bracket that would enable her to independently don and doff the headset, however she did not like the cosmetics of this. A phone on a gooseneck was then discussed and this was seen to be more cosmetically acceptable to her. The phone was also tilted up to enable her easier access to the buttons and reduce the strain on her neck.

Filing

Filing can require a person to be reaching and lifting at the end of their range of motion. This can also be a very asymmetric posture. Often people with limited range of motion and/or strength have trouble accessing a standard filing cabinet. Reaching to get the files in the back can be difficult and some drawers are difficult to reach. One item that can make this task easier is a lateral file cabinet. A lateral file cabinet does not require the person to reach far from midline for heavy files. Some people do not have the grip strength to grasp the files but have the strength to lift the files. One possible solution to this problem is to place the files in hanging folders and tie computer tie wraps through the front and back of each file. The person could put his hand through the wrap in front and in back of each folder and lift them out no grip strength is required.

Another filing item that can be useful for persons with limited range of motion is a lazy susan. These can sit on a desk or table and make multiple items accessible in a small space. The lazy susan can be spun on order to make the desired item accessible. Tub files on a desk can also be used to make files readily accessible.

Reading/Writing:

Reading and writing are usually performed in a forward leaning posture that can cause strain on a person's back or neck. One way to reduce the strain on a persons neck and back is to use a slant board which props the work up at a desired angle. These are available in several different sizes from 12"-24" long. Another option is there are tables which are primarily used for drafting that have tops that can be tilted at different angles. These, however, are much more expensive than a slant board. A catalog rack can be used for large manuals that have to be readily accessible. There are several devices available that can help a person grasp a pencil or pen. From large balls with a pen or pencil through them to splints where the instrument can be attached. Again depending on the disability the position of the wrist can be important. Depending on the person and the disability keeping the wrist in a neutral position might be less fatiguing over a long period of time.

## Discussion

The principles of ergonomics should be applied whenever possible in work site assessments to reduce the strain on the individual. However when dealing with the comfort of an individual, every person is different. The person should not be "forced" into the proper ergonomic position if they find that position to be uncomfortable. There are times when a person will be most comfortable in what appears to be an awkward position. For example, a person with a fused disk at C5-6 found that looking down at the keyboard put a lot of strain on his neck. If the keyboard was positioned below the front of the monitor in a vertical position this would reduce the strain on his neck but would increase the strain on his arms and shoulders when he accessed the keyboard. Some mobile arm supports (Ergo Arms) were attached to the desk that would support his arms at the elbows and reduce the strain on his arms and shoulders. While this by now means is an ideal ergonomic solution it is what worked well for this individual. In addition there are many devices that are "ergonomically" designed that may not always be appropriate for a particular person.

Jeff Symons
Department of Rehabilitation/C.A.R.E.
830 K Street Mall
Sacramento, CA 95814

15.3

# Utilizing A Rehabilitation Engineer As An Instructor In Undergraduate Occupational Therapy Courses

James A. Lenker, M.S.M.E. & Jo A. Schweitzer, OTR
Department of Occupational Therapy
University at Buffalo
Buffalo, NY

ABSTRACT

The American Occupational Therapy Association has established a special interest group for assistive technology in recognition of the increased utilization of technology as a tool for therapeutic intervention. In keeping with this trend, the Department of Occupational Therapy has been utilizing a rehabilitation engineer as an instructor who has both graduate and undergraduate teaching responsibilities. This paper outlines two undergraduate courses that are team taught by the authors: *Therapeutic Media I* and *Job Accommodation.*

## PART I: THERAPEUTIC MEDIA

### BACKGROUND

*Therapeutic Media I* is the first of three courses offered by the Department of Occupational Therapy which address the use of media as therapeutic resources for the occupational therapist. Though many instructional responsibilities are shared, the occupational therapist is primarily responsible for introduction of theoretical concepts and discussion of clinical implications of the material, while the rehabilitation engineer presents the laboratory exercises that require students to experience and apply the concepts being taught.

Topics covered in *Therapeutic Media I* include introductions to activity analysis, the theory of purposeful activity, and use of hand tools utilized in various therapeutic media. These topics are reinforced through laboratory exercises in woodworking, soldering, elementary electronics, switchmaking, and adapting battery-operated toys for single-switch use. All activities are analyzed and discussed in terms of OT theory and clinical application.

### OBJECTIVE

*Therapeutic Media I* is designed to address several of the topic areas required by the AOTA undergraduate course essentials. Students demonstrate competence in basic hand tool use as applied to adjustment of wheelchairs, construction of a woodworking project, soldering of electronic components, fabrication of an electronic device, and adaptation of a battery-operated toy.

### METHODS/APPROACH

Instructional approaches for each area of *Therapeutic Media I* are described below.

#### Activity Analysis

Lectures, individual assignments and small group activities involve analysis of purposeful activities. An initial activity analysis assignment is given as students observe a silent demonstration of soldering. The final activity analysis written assignment requires description of the fabrication process for the switch and electronic device project.

#### *Wheelchair Anatomy and Adjustment*

An introductory lecture describes and demonstrates basic wheelchair "anatomy" and mechanical adjustment. For the laboratory assignment, students work in teams to look at several variable features in chair design (e.g. sling vs. solid back, solid vs. pneumatic tires, elevating vs. standard footrests, etc.) and explore various mechanical adjustments for manual wheelchairs (e.g. footrest height, armrest height, etc.).

#### *Woodworking*

Classroom demonstration of the appropriate use and application of woodworking tools precedes a two-part laboratory project. Students follow an instructor-provided plan to measure, cut, assemble, sand and finish a hand loom and an adjustable stand for the hand loom. Students use their own hand looms and adjustable loom stands for weaving projects in *Therapeutic Media III.* The concept of "accommodation" is introduced with the standing frame, which provides adjustment for both loom height and angle. The capacity for adjustability and adaptability of a tool or piece of equipment is stressed as an important clinical consideration when using therapeutic media.

#### *Soldering, Switch and Call Box Fabrication, and Toy Adaptation*

Lecture and hand-outs describe soldering, fabrication of switches and simple electronic devices, and adaptation of battery-operated toys for single switch use. Each student team is required to fabricate an operational mercury bulb switch, a light/buzzer "call" box, and a battery interrupter for single-switch adaptation of a battery-operated toy. The switches and adapted toys used for demonstration are borrowed from an OT clinical setting, which emphasizes the application of the material being described and demonstrated.

#### Relevance of "Technology" to Occupational Therapy

Students do a clinical observation at a job training site that features computer training for young adults who have mild cognitive disabilities and a fee-for-service wheelchair seating and positioning clinic. Supplemental readings introduce the use of assistive technology as a function-enhancing tool for some individuals. Opportunities for undergraduate OT student involvement in a technology-related area are also presented.

## RESULTS

The course as described above has been taught twice (1990 and 1991) to a total of 99 students. Many of the students are initially apprehensive about working with tools (e.g., soldering and woodworking) that are relatively unfamiliar to them, but most emerge from the course with a sense of confidence that these skills weren't, "so difficult after all." Music to a teacher's ears! The complementary elements of course content, instruction mode (lecture/lab), and instructors' professional backgrounds are very effective, and the course has been very popular.

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## PART II: JOB ACCOMMODATION

### BACKGROUND

*Job Accommodation* is part of a federally-funded, Vocational Traineeship Program that provides theory and practical application of vocational training to undergraduate occupational therapy students. There is a shortage of occupational therapists who are qualified to work in vocational settings, and the three-semester Vocational Traineeship Program was established in response to this growing need.

The *Job Accommodation* course is the third of the three-semester sequence of courses in vocational training issues. The first semester involves an introduction to vocational evaluation, training and rehabilitation, and the second semester requires a ten-week field work placement at a vocational training site.

### OBJECTIVE

*Job Accommodation* focuses on improvement of the working efficiency of individuals who have a physical, cognitive and/or psychosocial disability. Topics covered in the course include:

1. Use of personal computers for word processing in work settings.
2. Information for locating commercially available services and assistive devices.
3. Ergonomics of workstation design.
4. Job task and worksite assessment.
5. Accessibility of the workplace.
6. Psychosocial issues that affect acceptance of adaptations to an individual's environment.
7. Clinical assessment of individuals in need of customized work stations.

Each student must complete a term project that requires working with an individual who is involved in a vocational setting. The project goal is to improve client efficiency through task restructuring, improved workspace arrangement, recommendation or design of an assistive device, or recommendation for improved building accessibility. Students are encouraged to work cooperatively with the client and the employer/ trainer in order to develop suggestions that are appropriate to the client.

### METHODS

The course was developed and is team-taught by a rehabilitation engineer, an occupational therapist and an industrial designer, and each faculty member has had an integral role in the development and instruction process. A graduate seminar format is used in order to maximize individual involvement and group discussion.

The first half of the semester features brief didactic presentations followed by general discussions that enable students to compare their previous experiences with the material that is being introduced. Student awareness of community resources is broadened by including a seminar at the local V.A. Hospital, a mini-conference sponsored by the regional chapter of the National Rehabilitation Association, and a workshop on wheelchair seating and positioning held at a university-based wheelchair seating clinic.

Student projects are assigned at mid-term, and subsequent class sessions are devoted almost exclusively to group problem-solving. Where possible, each student videotapes his/her client at the client's worksite, which enables classmates and faculty to participate meaningfully in the process of assessment, problem definition and problem resolution. Final project reports consist of summary recommendations directed to the client and employer/job trainer.

### RESULTS

*Job Accommodation* gives students a directed clinical experience that applies their accumulated knowledge of OT principles to the needs of persons in specific vocational settings. The term projects provide several unique experiences: application of OT theory and practice to vocational assessment and adaptation, direct contact with disabled individuals who are in vocational settings, and experience working with employers of disabled persons. With the addition of a rehabilitation engineer and an industrial designer to the course faculty, students gain experience working as part of a multi-disciplinary, problem-solving team. This approach mimics the realities of professional life where OT's are exchanging ideas with persons from disciplines outside of occupational therapy.

The course also bridges the gap between undergraduate and graduate instruction. For most of the students, the smaller enrollment and seminar format is their first taste of the graduate student "experience". The course was taught for the first time to 5 students in 1991, and the course will be continued in 1992 and 1993. Students responded enthusiastically to the course, which reflected their interest in the topic areas, the shared expertise of the multidisciplinary instructional team, and the open-discussion format of the class.

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## DISCUSSION

*Therapeutic Media I* and *Job Accommodation* successfully combine academic education and pr^o^ clinical experience by augmenting traditiona^l^

15.4

# Back Muscle Activity: A System for EMG Measurement and Analysis in the Workplace

Daniel P. Gottesman, Gerald Weisman, James P. Tranowski
Vermont Rehabilitation Engineering Center

Abstract

An integrated hardware and software system has been developed, that uses electromyography (EMG), to assess back muscle activity in the workplace. It is a portable system for collecting dynamic surface electromyography data that can be worn in many situations without affecting normal activities. The device is designed to assess a worker's level of back muscle activity, over a period of up to 8 hours, during the performance of his/her job. The data collected may be represented by graphical output, designed for this application, that provide a clear picture of the subject's back muscle activity. This information may be used in comparing the back muscle activity levels between jobs, or in evaluating ergonomic improvements in a job.

**Background**

Low back pain (LBP) is a major problem throughout the industrialized world. High levels of muscular exertions in the back have been shown to be risk factors LBP (Chaffin & Park 1973). Electromyography (EMG) is widely recognized as a tool for the assessment of relative magnitudes of muscular forces. "Surface electromyography is an important method for gauging the forces generated in the underlying muscles." (Stokes 87)

Considerable research correlating EMG with muscle forces has been done on static postures where it has been shown that EMG amplitude correlates with force (Chaffin 1984). Use of EMG to analyze dynamic activity is more complicated. However, it is clear that excursions of the EMG signal do represent innervation of the muscle to exert force (Corlett 1990).

**Objective**

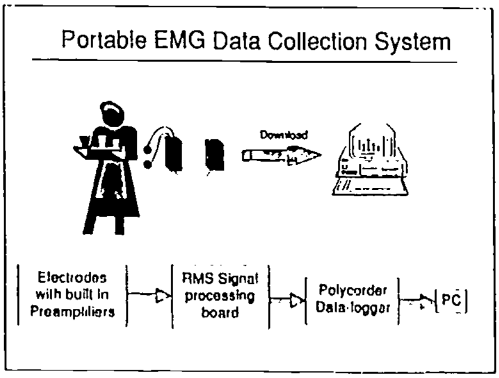
The objective of this research was three fold. First, to develop a portable EMG data collection system to measure back muscle (Erector Spinae) activity in the workplace without restricting workers' activities. Second, to develop analysis methods to extract meaningful information from the data that is collected. Third, to develop graphical presentation methods to make the data collected accessible and comprehensible. The system should allow the comparison of muscle activity for the same worker across jobs or for the same job across workers. These comparisons can be very useful in job assessment, and job redesign efforts.

**Rationale**

This system will help in determining the LBP risk levels of existing jobs, as well as aid in designing jobs to be less stressful to the back. The benefits will thus be a reduced risk of disabling low back pain, which can be appreciated across many levels of our society, including workers, employers and society as a whole. The worker will have a lower risk of injury, the employer will have lower medical costs, and society will be less burdened by the costs of disability.

**Design**

The system (Figure 1) has been designed with great care to minimize or eliminate some of the problems that are often faced by researchers in EMG data collection. By use of the Davicon/Fasstech active electrodes, amplification and RMS hardware we are able to obtain a signal which is clearly associated with the subjects' activity. This is due to a few factors. Preamplifiers are attached directly to the electrodes reducing the problems of interference from environmental signals. The hardware also has built in analog filters which help to eliminate interference that would otherwise degrade the data. These features together with the RMS signal processing gives us a relatively smooth ard surprisingly comprehensible signal. The use of a battery powered data collection system allow data collection in the workplace while the worker is free to do his/her job.



**Data Collection**

The sampling and data collection is done with a "Polycorder", (Omnidata, Utah), which is a 3.5 lb battery powered data logging device. The Polycorder is able to store approximately 400 Kbytes of data. We have chosen to sample at 10 Hz. which allows us to collect data for up to 5.5 hours.

To facilitate comparison of EMG values across time and subjects, resting level and a standard exertion (Sub maximal) samples are collected at the beginning, end and intermediate intervals during each data collection session. These reference level samples are used for normalization of the EMG data, which allows us to compare data from different sessions.

**Analysis**

The analysis has two primary foci. They are magnitude and repetitiveness. Repetitiveness, called task frequency, is determined by counting the times the EMG signal trace crosses the mean value during a time window. The time window for repetitiveness is one minute, and has as its center the data point being evaluated. The mean is calculated for the entire sample. The magnitude function is also smoothed using a sliding time window, in this case the duration is specified by the user, and can be as short as a few data points or as long as 60 seconds.

The smoothed functions for repetitiveness and magnitude are processed further into chronological files of categorical data for both left and right sides. The magnitudes are assigned to 1 of 8 magnitude bins and the frequencies to 1 of 4 bins. It is this binned data that is used to create the graphical image described in the next section.

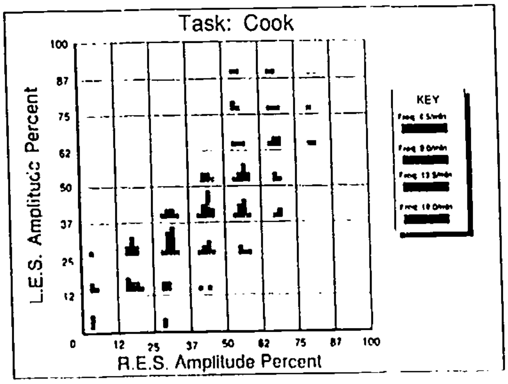



**Figure 2 Graphical Output**

**Graphical Output**

A graphical presentation method has been developed to present the data for one or more data collection sessions in a single graphic. ( See Figure 2 ) The X and Y axis are EMG magnitude on the right side and left side respectively. Each of these are divided into a number of categories or bins as referred to in the analysis section above. Within each cell there is a four bar graph, with each bar representing a task frequency. The bar height represents the number of samples or the total amount of time that occurs in the category. The graphic clearly illustrates whether the activities were primarily symmetrical, whether there was a lot of time spent in high level exertions, and whether the repetitiveness for back exertions in the job is high or low.

**Development**

The development of the system was an evolutionary process. The method for calculating the repetitiveness evolved from observation of data traces and their correlation to the tasks that were being done at the time of recording. Other methods were tried but found to be less useful.

Data collection at lower frequencies, including 2 Hz., was attempted with the goal of extending the total data collection time, now limited by the Polycorder's memory. A FFT analysis was done on a sample collected at 1000 Hz and it was determined that sampling of the RMS signal should not be done at a rate lower than 6 Hz. Ten Hz. was chosen as the data collection rate, adding a safety factor.

**Evaluation**

The system has been tested in a few situations. Laboratory testing included different evaluations. In one of these a subject did a few simple activities,00 including carrying different weights and hand transfer tasks using different weights. This data was then plotted and visually inspected to determine whether the EMG data reflected the tasks being done. The data did reflect the tasks being done. A section of this data plot is reproduced in Figure 3. In another laboratory study subjects did repetitive bending tasks to lift weights from floor level to waist level. In this study the task repetition rate could be clearly seen in the data.

A field test was done with a cook as the subject. The equipment and software functioned well. An example of the data from this subject can be seen in Figure 2. Currently a large scale field evaluation

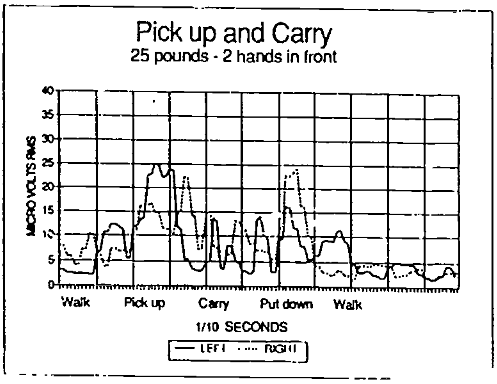



**Figure 3: Laboratory Data**

**Discussion**

Collecting EMG data for a prolonged period raises the issue of baseline drift. This has been addressed by periodically collecting a sample of resting level EMG. These periodic resting level samples are used when the data in normalized.

Window averages are used in the analysis to facilitate understanding of the gross behavior. They focus attention on groups of contractions rather than single muscle contractions, allowing conclusions about work done during a period of time.

**Conclusion**

A method has been developed for acquiring and analyzing EMG from the field. The system is effective because it records data about the EMG of the wearer, while not disrupting normal daily activity. The method can provide an objective statement about the wearer's back muscle activity.

By collecting data over a long period of time (hours) significant information about the muscular activity of a worker throughout his/her shift may be obtained. The associated software, developed at the Vermont REC, may be used to present a clear graphic image representing back muscle activity during the job.

There is potential for further development of the system. Possible future directions include: linkage with other measures of work load, and/or a video tape system to isolate high stress aspects of a job. The hardware and software could also be used in the assessment of ergonomic stressors to other injury prone areas in the body, including the upper extremity.

Acknowledgements

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Daniel P. Gottesman
Rehabilitation Engineering Center
Arnold 5 - DU
University of Vermont
1 South Prospect St.
Burlington, VT 05401

# A survey on the usage of bathroom ixtures by disabled people

Pascal Malassigné, IDSA
Clement J. Zablocki VAMC, Milwaukee, WI

Thomas L. Amerson, Ph.D
Rehabilitation R&D Center, Atlanta VAMC, Decatur, GA

## ABSTRACT

A survey was conducted to determine the bathroom fixtures usage preferences by 800 disabled people. Although there was a relatively wide range of responses because of the various type of disability of respondents, strong preferences and approaches were noted for bathtubs, showers, lavatory or toilet fixture configurations. Implications for design improvements to these fixtures are indicated in this paper.

## BACKGROUND

Although there have been a few investigators addressing human factors considerations in the design of bathrooms and bathing fixtures (1-3), surprisingly little work has been done to determine the use or useability of such facilities by people having paralysis or restrictions to mobility. In 1990, the authors conducted a survey to determine how bathroom fixtures were used by people exhibiting paraplegia, quadriplegia, hemiplegia, amputations, or other similar restrictions to mobility. This report describes their study and findings.

## RESEARCH QUESTIONS

Several key research questions surfaced at the outset of the study.

1. Demographics. With a large sample of subject, what are the relative proportions of the restrictions to mobility? What are the age groups represented in the sample? What types of wheelchairs, electric or manual chairs, crutches, canes, or other mobility aids were in use? What are the types and prevalence of home modifications made to facilitate the use of the bathroom?

2. What are the types of approaches to bathtubs for people using wheelchairs, and how do they differ from the approaches of those w , are able to walk with assistance?

3. How effective is the use of such transfer aids as grab-bars in making safe transfers to and from the bathtub or the toilet?

4. For people with good upper body mobility, do they prefer drying themselves in or outside the bathtub? Do they require assistance in drying?

5. What are the design features of the lavatory which are preferred or which present problems to users of wheelchairs or other mobility aids?

6 What are the toilet transfer preferences for those who use wheelchairs?

## METHOD

In order to acquire a large sample size of the target population, it was necessary to obtain the cooperation of an association which could easily and quickly provide a random listing of disabled people. Paralyzed Veterans of America (PVA) is such an association with 15000 members. PVA was approached regarding the study and generously provided a list of 1900 names randomly selected from the membership.

A questionnaire was constructed containing 49 questions regarding the use of bathroom fixtures. Many of the questions were enhanced with the use of illustrations or figures. Typically, the questions asked for responses of perceived difficulty followed by a Likert scale having four points: "easy," somewhat easy," somewhat difficult," and "difficult." A sample of the questions and the use of illustrations is provided in Figure 1. Every effort was made to make the questions readable, easily understood, and appropriate to the research questions.

Franked, return-addressed envelopes were included with each questionnaire so that no cost was incurred by the respondents except for their time. A cover letter to the questionnaire was provided by the researchers assuring the respondents of their anonymity and freedom to decline from participating without risk to their PVA affiliation or their veterans' benefits.

## RESULTS AND DISCUSSION

Of the 1900 questionnaires sent to members of PVA, 800 were completed and returned. This exceptional return rate of 45% is, undoubtedly, an indicator of the interest and concern generally held for improving bathroom fixtures among the subject population.

### Demographics

Since the participants in the study were acquired through Paralyzed Veterans of America, it is hardly surprising that the respondents were predominantly male (95%). The female military population comprises a relatively small part of the total military force. Also, spinal cord injury, cerebral vascular accidents, and other forms of paralysis are generally more prevalent among the male population.

Of those responding to the questionnaire, 40% were less than 50 years of age. Thus, the opinions or experiences expressed may be somewhat more reflective of an older population.

The causes of disabilities were distributed as follows 46% paraplegia, 16% quadriplegia, 27% multiple sclerosis, 4% poliomyelitis, and 7% hemiplegia or amputation

Of the respondents who used a wheelchair, 83% used a manual chair and 17% used an electric chair. Among those not using a wheelchair, 28% used a cane or crutches for assistance.

The majority of respondents lived with their family, and among those, 70% had made modifications in their homes to help them perform their daily activities more independently.

One of the questions related to the respondents' satisfaction in toileting, showering, or bathing independently. The participants were nearly evenly split in their response to this question: 54% replied that they were satisfied, 46% said that they were not satisfied with their usability of the bathroom.

### *Bathing*

To ease data reporting, all responses to the questions have been "collapsed" to reflect a two point scale, "easy" or "difficult."

There were a large number of questions concerned with walking and wheelchair approaches to the bathtub. Illustrations of three different approaches to the bathtub were provided in the questionnaire. Two bathtubs were shown in these illustrations; one had a platform at one end, but the other had no platform. For the bathtubs having no platform, 74% of the respondents indicated that they would have moderate to high levels of difficulty making a perpendicular wheelchair approach. The parallel approach appears to be preferred with only 41% of the respondents indicating any difficulty. This advantage in making a parallel wheelchair approach disappeared with the introduction of the platform to the bathtub: 70% found difficulty with an "angled" approach, and 63% said the parallel approach would be difficult. The respondents making a walking approach to the bathtub were somewhat more evenly distributed in their preferences. In approaching bathtubs without a platform, 55% said the perpendicular approach would be difficult and 68% responded nat the angled approach would present difficulty. The addition of the platform to the bathtub left 57% of these walking respondents finding difficulty in the angled approach and 48% having difficulty with the parallel approach.

The line of questioning continued by asking the relative difficulty encountered with transfers and walking approaches to the bathtub rim and whether the presence of grab-bars had an effect. A great majority of those making a transfer from a wheelchair to the bathtub rim stated that doing so without a grab-bar would be difficult (89%) but only 50% found such transfers to be difficult with grab-bars provided. The respondents walking to the rim of the bathtub responded in a surprisingly similar fashion: 86% thought the transfer would be difficult without a grab-bar while only 43% thought the transfer would be difficult with a grab-bar.

Making the transfers from the rim to the bottom of the bathtub and the return to the rim also appears to be affected by the presence of the grab-bars. When transfering to the bottom of the bathtub, 88% considered the task to be difficult without the grab-bars while only 43% considered this transfer to be difficult if grab-bars were provided. Making the return to the rim of the bathtub from the bottom elicited similar responses: 88% found such transfers to be difficult without the grab-bars, and 52% of the respondents considered the transfer to be difficult with the use of the grab-bars.

The participants of the study tended to use a seat in the bathtub (63%) and were satisfied ("yes" or "no" response) with its performance (72%).

#### *Usage of faucets*

Respondents to the questionnaire were asked to rate the difficulty to control the faucets in a bathtub based upon location (inside or outside) and control options (single control faucet or separate temperature controls): 78% considered the inside single control to be "easy" to operate; 61% thought the inside separate temperature controls were easy; the outside single control was rated easy by 57% of the respondents; and the outside separate temperature controls were rated as easy by only 42% of the respondents.

#### *Preferences for drying off*

After the bath, 59% of the respondents preferred drying off inside the bath. Assistance in drying was required by 38% of the respondents.

### *Usage of the lavatory*

The vast majority of respondents (91%) preferred to use an open lavatory accommodating the wheelchair because of the improved access to the faucets.

No meaningful differences were reported concerning the preference for "round," "indented," "blade," or "single lever" faucets. The respondents reported all of these faucet designs to be easy to use.

### *Usage of the toilet*

Respondents using wheelchairs were asked their preferences in making the transfer to the toilet. Little difference was noted among the frontal approach at an angle (29%), the forward transfer (29%), and the side approach at an angle (28%). The side transfer was not as favored (14%).

Toileting activities by those using a wheelchair consume a substantial amount of time for the sample population, however. Only 15% of the sample emptied their leg bags of urine into the toilet once a day, 30% reported three empties per day, 26% reported four empties per day, and 29% reported five bag empties per day. The bowel care programs used by the respondents had 53% using the toilet daily, 32% using it every 2 days, and 15% using it every 3-5 days.

The collection of these data has enabled the authors to acquire a more complete understanding of the usage bathroom and conventional bathroom fixtures by disabled people. This information is used by the authors as the basis of new, more ergonomically designed and safer bathrooms fixtures.

*ACKNOWLEDGEMENTS*

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The views in this paper do not necessarily represent those of the Department of Veterans Affairs or the United States Government.

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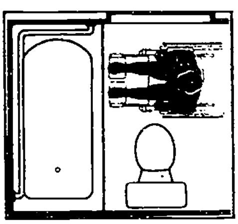
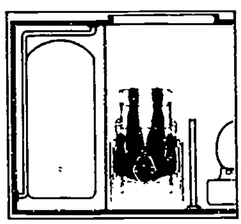
**Pascal Malassigné**
Clement J. Zablocki V A M C, Milwaukee
5000 W. National Avenue
Milwaukee, WI 53295

**Figure 1: example of two illustrated questions**

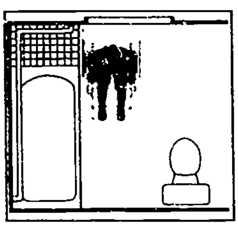
1. **Rate the difficulty of approaching the side of the bathtub from the positions seen below.** Circle 1,2,3 or 4 (go to question 2 if not applicable)



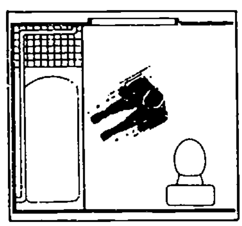
1. easy
2. somewhat easy
3. somewhat difficult
4 very difficult



1. easy
2. somewhat easy
3. somewhat difficult
4. very difficult



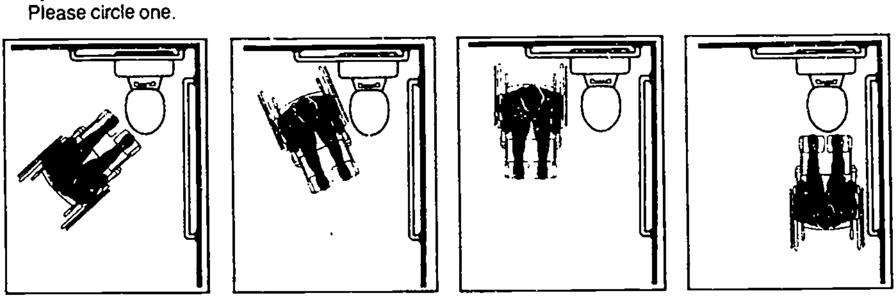
1 easy
2. somewhat easy
3 somewhat difficult
4 very difficult



1 easy
2. somewhat easy
3. somewhat difficult
4 very difficult

### Usage of the toilet

1. If you use a wheelchair, do you approach the toilet from one of the positions shown below in 1,2,3 or 4? Please circle one.



1 2 3 4

2. Regardless of your approach to the toilet, rate the difficulty of transfering onto the seat from a wheelchair? ______________________________

15.6

# AN ADAPTIVE TAPE-TRIMMING JIG

Glenn Hedman, M.Eng.
Assistive Technology Unit
University Affiliated Program / University of Illinois at Chicago
Chicago, Illinois USA

## ABSTRACT

An adaptive tape-trimming jig is described, which utilizes a linear positioning slide fabricated from carpenter's layout tools. The adapted slide offers a slip-fit line of travel, with adjustable friction. The slide mechanism may be useful for designs other than the tape-trimming jig.

## BACKGROUND

The ability to return to work after a job-related injury involves not only rehabilitation, but elimination of the circumstances which contributed to the injury and the modification of any job stations which may cause the injury to re-occur as well. Just as important is the motivation to return to work on the part of the worker.

A Worksite Modification Evaluation was requested by a private insurance company, trying to assist an injured worker in returning to the job site. The job site was an abrasive disc refinishing company. The worker in question was a 45-year old woman who injured her right hand and wrist after approximately six weeks on the job as one of three Plater Helpers. The injury had apparently occurred in an area outside her specific workstation, and involved abrasions of the right hand and wrist with several foreign bodies (pieces of wire) having to be removed. The client had been off work for approximately 11 months before the referral, but was still motivated to return to work. During that time, the client had undergone exploratory surgery, nerve blocks, occupational therapy, and physical therapy.

Job tasks of the Plater Helpers include:

- Masking of abrasive disc with industrial tape
- Trimming of 1/4"-wide margin at inside and outside edges of disc to expose the metal at these areas
- Installation of 1/4"-20 bolt through center of disc
- Cleaning of disc in sandblaster
- Polishing of disc on machine lathe

The discs being handled varied from approximately 5" in diameter, weighing less than 2 lbs. to approximately 12" in diameter, weighing over 20 lbs. A Plater Helper may handle 15 to 20 discs per day.

All job tasks seemed to involve excessive work on the part of the worker's injured right upper extremity. Assistive Technology interventions which were recommended included:

- Use of industrial-grade tape dispenser to eliminate current "slicing off" of individual pieces of tape
- Fabrication of custom-designed tape-trimming jig
- Fabrication of disc/bolt holder to eliminate need for handling of two wrenches simultaneously
- Fabrication of disc holder for inside of sandblaster so that discs would not have to be held by worker
- Use of carpenter's sandpaper rubber molding to provide stabilization of sandpaper/dampening of vibration. Also, use of rubber mallet to release clamp lever

The tape-trimming jig is the intervention which utilizes the adjustable slide positioning components described in this paper.

## DESIGN OF TAPE-TRIMMING JIG

The client, and the other two Plater Helpers, performed the tape-trimming in the same manner: scoring an arc in the tape with a single-edge razor knife, and then re-positioning the disc and re-scoring until the arc was cut all the way around the disc. This method was used on all discs, regardless of size or weight. Design factors which had to be considered included:

- Ability to perform tape-trimming with reduced work on the part of the injured right upper extremity
- Use of device by all three Plater Helpers
- Handling of all disc sizes and weights
- Possible increases to quality
- Possible increases to productivity
- Durability of components
- Serviceability of parts
- Cost of jig

Clearly, the method of actual tape-trimming needed to be changed. The existing method of scoring the tape necessitated firm pressure of the blade of the razor and the re-positioning of heavy discs. Design of the tape-trimming jig focused on the possibility of making the cutting edge stationary, and having the disc rotate using a mechanism which did not involve excessive work on the part of the right upper extremity.

A circular, rotating disc support surface was specified, attached to a rectangular base with a turntable ball bearing assembly. A linear slide, allowing precise positioning of the cutting edge, could be located above one side of the disc support, enabling a score to be made at any radius required.

## FABRICATION

The rectangular base and circular disc support were fabricated from laminated pressboard sink cutouts, obtained from a local lumber yard (Figure 1). The ball bearing assembly was obtained from an industrial supply company. A non-skid surface was glued to the top of the circular disc support surface to prevent discs from sliding, and rubber feet were added to the bottom of the base to stabilize the entire unit.

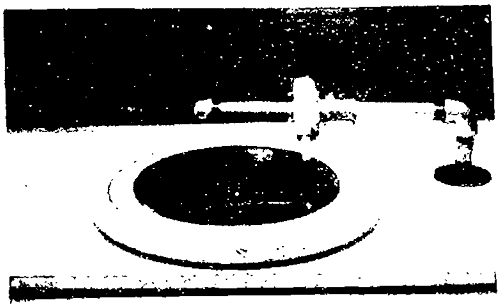


Figure 1

The positioning of the cutting edge was achieved by the modification of one piece of a carpenter's trammel head set. The trammel head set is typically attached to a standard piece of galvanized pipe to enable a large radius to be drawn on building materials. One piece of the set accepts a steel pivot point, the other a rectangular piece of chalk. A thumbscrew on each piece allows the radius to be set before drawing begins.

For the tape-trimming jig, the trammel head piece normally holding the chalk was modified (Figure 2). The bracket accepting the chalk was removed, leaving a flat surface. A piece of hollow delrin rod was flattened on one side, allowing attachment to the trammel piece via two machine screws and 10-32 tapped holes in the delrin. An additional screw was installed through the delrin to keep the knife from rotating.

Figure 2

A key modification to the trammel piece involved the replacement of the thumbscrew with a threaded ball plunger. This ball plunger, with nylon insert to allow exact positioning, provides adjustable, yet constant pressure on the pipe to fine-tune the friction of slip-fit on the pipe.

To use the tape-trimming jig, the client positions the disc at the center of the circular disc support. The blade handle is then positioned laterally at the required radius of the cut (Figure 3). Once the radius has been determined, the client tilts the blade downward to meet the tape surface and rotates the circular disc support clockwise until the score is made completely around the disc (Figure 4). The uniform cut greatly increases the quality of the job task, as the radius is set and does not vary as it did with the previous arc method. After both inner and outer scores have been made, the client lifts off the excess tape.

Figure 3

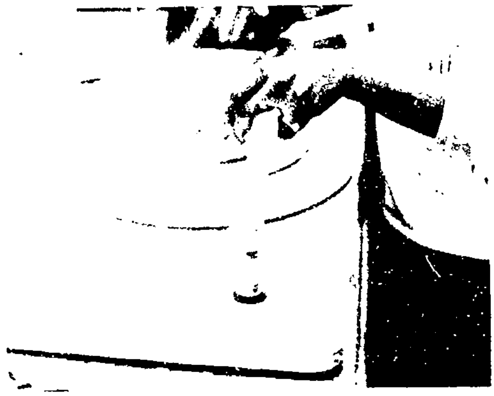


Figure 4

CONCLUSION

A tape-trimming jig was fabricated, as part of an array of Assistive Technology equipment interventions to reduce the work required of an injured worker's right upper extremity and allow a return to work. The jig was fabricated with inexpensive parts, available at hardware stores, lumber yards, and adaptive equipment and industrial supply companies. Total cost of the materials involved in the tape-trimming jig was approximately $90, with approximately three hours of fabrication time required. The linear slide adjustment of the jig may be applicable to many other designs.

ACKNOWLEDGEMENTS

The work of the Assistive Technology Unit is made possible by the Illinois Department of Rehabilitation Services (DORS), the Illinois Department of Mental Health and Developmental Disabilities (DMHDD), the United States Department of Health and Human Services - Administration on Developmental Disabilities (ADD), and the University of Illinois at Chicago.

**SUPPLIERS**

McMaster-Carr Supply Company
P.O. Box 4355
Chicago, IL 60680-4355
(708) 833-0300

| Item | Item # | Unit |
|---|---|---|
| Trammel Head | 1920A42 | set |
| Ball plunger | 3408A39 | each |
| Knife | 38995A71 | each |
| Knife blades | 38995A73 | package |
| Delrin rod | 8627K62 | 5'-length |
| Ball bearing unit | 6031K19 | each |

Fred Sammons, Inc.
P.O. Box 32
Brookfield, IL 60513-0032
(800) 323-5547

| Item | Item # | Unit |
|---|---|---|
| Non-skid pad | 6563-01 | each |

Hardware store
- Pipe
- Flange
- 90 degree elbow
- Cap
- T-nut fasteners
- 10-32 round head screws
- #10 washers
- Rubber feet

Lumber yard
- Laminated pressboard sink cutouts

Glenn Hedman
Coordinator
Assistive Technology Unit
University Affiliated Program
University of Illinois at Chicago (M/C 627)
1640 West Roosevelt - Room 412
Chicago, IL 60608-1396
(312) 413-1555 (Voice)
(312) 413-0453 (TDD)
(312) 413-1326 (FAX)

# AN ADAPTED DOCUMENT CART

Glenn Hedman, M.Eng.
Assistive Technology Unit
University Affiliated Program / University of Illinois at Chicago
Chicago, Illinois USA

## ABSTRACT

Design and fabrication of an adapted document cart is presented. This worksite modification was performed for an individual with cerebral palsy, who needed surfaces to provide stability while storing papers on high shelves in a federal docun.ent storage facility.

## INTRODUCTION

Referrals for worksite modification often involve the modification of devices already at the job site. These modifications made need to be made on a device used by the specific employee, or to those shared by all employees.

A Worksite Modification Evaluation referral was made to the Assistive Technology Unit (ATU) o the University of Illinois at Chicago (UIC) University Affiliated Program (UAP). The referral was made by a local community agency, as it was assisting the Illinois Department of Rehabilitation Services in placement of an individual at a federal document storage facility in Chicago.

The client referred is a 22-year old male with cerebral palsy, who is ambulatory. The community agency had been providing a job coach to assist the client in learning the job tasks and in monitoring the quality of the work performed. The specific job in question was that of Drop Filer, which includes the following tasks:

- Load document cart with papers to be filed
- Locate aisle where correct storage box is located
- Locate correct storage box on shelving units
- Pull storage box from shelf and insert document

For this job, all Drop Filers used a government-issued document cart. Standard procedure included each Drop Filer being assigned a specific cart for their exclusive use. Carts were stored in a common parking area when not in use.

The document storage area is comprised of several aisles with metal storage shelves on both sides, each aisle only 28"-wide. While the shelving units are 15 to 20 feet high, Drop Filers need access to only the bottom 7 shelves, the highest being approximately 7 feet high. When storing documents on the higher of the 7 shelves, Drop Filers use the fold-out, two-step ladder of the document cart. The step ladder allows the Drop Filer to stand either 11" or 22" above the floor to reach the correct storage box.

Although the client is ambulatory, he did have the need for assistance in maintaining his balance when using the cart's step ladder. At the Worksite Modification Evaluation, dimensions were taken for the appropriate height of side and front support for the client as he used the cart's step ladder (the client stated that front support was needed only as the top step was being used). These dimensions were 34" and 40", respectively. The ATU requested that the document cart reserved for use by the client be allowed to be removed from the premises for modification. After gaining this approval, the ATU then set out to design an adaptation to provide the needed support which would not sacrifice the portability of the document cart.

## DESIGN

Factors included in the design of the document cart adaptation included:

- Location of support members
- Portability of cart
- Weight of adaptation
- Adjustability of supports
- Durability of components
- Serviceability of parts
- Cost of materials

The dimensions of the support surfaces translated to a three-sided frame, with side support present at two levels (to provide appropriate height support when each of the two steps were being used).

In order to maintain the portability of the document cart, attachment to the fold-out step ladder was considered to be the most appropriate option. By doing so, the relative dimensions between the support surfaces and the steps would be kept constant, and one action on the part of the client would be required to set-up or fold the steps. Attachment would be achieved through affixing the frame to a block of wood, and attaching the block of wood to the bottom supports of the fold-out steps. Although the steps would no longer fold entirely into the body of the document cart, the frame and steps would be compact enough to maneuver into and out of the storage aisles.

Aluminum frame components were specified to reduce the overall weight of the assembly. Modular fittings were included to allow adjustment of the support locations. The modular fittings would also allow easy replacement or further adaptation.

Prior-approval for the cost involved in the adaptation was requested and obtained from the client's DORS counselor.

## FABRICATION

Using commercially-available aluminum tubing and fittings, a frame was constructed which duplicated the support surface dimensions taken at the Evaluation (Figure 1). Frame components were 1" OD aluminum tubing, and 1" ID aluminum crossover-fittings and tee-fittings. Additional side components were added for structural support.

Figure 1
Crosspieces were added at the bottom of the frame, which were attached to a piece of 2" x 10" stair joist material, trimmed to fit the available space at the step ladder support legs. The wood block was then attached to the support legs (Figure 2). Long-tangent U-bolts were used at both attachment points, to accommodate the tubing diameter and the thickness of the wood block.

Figure 2
Since all components of the frame are located at or to the rear of the existing step ladder pivot bolt, all support legs lift upward when the frame is tilted forward, allowing the cart to be fully-mobile (Figure 3).

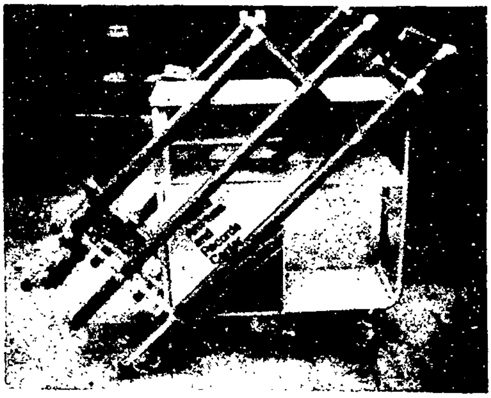


Figure 3
Cylindrical foam insulation was installed over the exposed tubing sections, for the client as well as to protect the shelving units from scratches (Figure 4). End caps were added at the ends of the tubing, to protect against cuts.

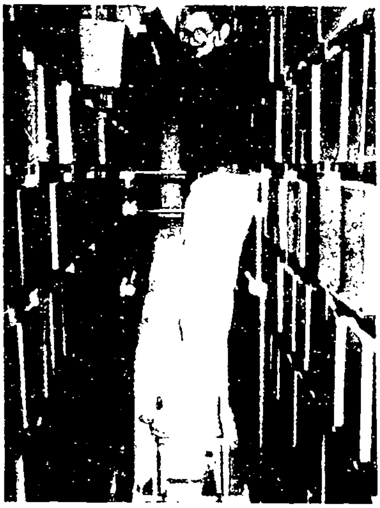


Figure 4

## CONCLUSION

Independent, safe use of a document cart was achieved through adaptation using lightweight aluminum tubing and fittings, foam insulation, and end caps. Total cost of the materials involved in this worksite modification was approximately $285, and about 4 hours fabrication time was required. The client's supervisor indicated that the same modification would be beneficial to all Drop Filers.


## ACKNOWLEDGEMENTS

The work of the Assistive Technology Unit is made possible by the Illinois Department of Rehabilitation Services (DORS), the Illinois Department of Mental Health and Developmental Disabilities (DMHDD), the United States Department of Health and Human Services - Administration on Developmental Disabilities (ADD), and the University of Illinois at Chicago. Support for the materials involved in this application came from Illinois DORS.

The fabrication skills of ATU Technician James Bullock were important for the successful implementation of this device.

**SUPPLIERS**

McMaster-Carr Supply Company
P.O. Box 4355
Chicago, IL 60680-4355
(708) 833-0300

| Item | Item # | Unit |
|---|---|---|
| Tubing | 4699T14 | 10'-lengths |
| Short crossover fittings | 4698T42 | each |
| Tee fittings | 4698T91 | each |
| End caps | 4936T196 | each |
| Long-tangent U-bolts | 8875T52 | each |

Hardware store
- Chair leg rubber tips
- Cylindrical foam insulation
- 3/8" ID washers

Lumber yard
- 2" x 10" stair joist material

Glenn Hedman
Coordinator
Assistive Technology Unit
University Affiliated Program
University of Illinois at Chicago (M/C 627)
1640 West Roosevelt Road - Room 412
Chicago, IL 60608-1396
(312) 413-1555 (Voice)
(312) 413-0453 (TDD)
(312) 413-1326 (FAX)

15.8

# Hands-Only Operated Electronic Industrial Sewing Machines

Dominic P.K. Cheng
Rehabilitation Engineering Centre
Hong Kong Polytechnic
Hung Hom, Hong Kong

## Abstract

Wheelchair users cannot use an electronic industrial sewing machine because it requires both hand and foot to operate. The approaches taken to convert two types of machines from different manufacturers for hands-only operation were described. Four converted machines have been successfully used since 1989 in a sheltered workshop for both training of and production work by wheelchair users.

## Background

Electronic industrial sewing machines are used extensively in modern garment industry for increased productivity and improved quality. Unlike their senior electric sewing machines, these newer machines have better speed control and offer a wide range of programmable features such as speed range, acceleration profile, automatic reverse stitching before forward stitching etc. Unfortunately, common to all motorized industrial sewing machines, the right leg is required to operate both a foot-pedal and a presser-foot lifter knee-pedal. When the foot-pedal is pressed forward, the sewing speed increases and when it is pressed backwards, sewing stops and automatic reverse stitching is activated if programmed, before both upper and lower threads are cut by a moving-knife under the feed-dog. The presser-foot is raised or lowered by either a hand-operated lever or a knee operated pedal. The hand-operated lever is used only occasionally because the knee pedal requires less effort to operate and it also frees both hands for increased productivity. To further minimize physical efforts and increase efficiency, a presser lifting solenoid option is available. The electric solenoid is activated by a sensitive knee-operated pedal switch.

## Statement of the problem

Is it possible for a person who has lost the function of both lower limbs to operate an electronic industrial sewing machine? In other words, is it possible to modify an electronic industrial sewing machine so that it can be operated easily by a person with either only one or both functioning upper limbs?

## Rationale

Considerations when modifying electronic industrial machines are:

1. Easy operation with either one or two hands.
2. The modification must not interfere with sewing operations.
3. The modification must neither void the warranty of the sewing machine supplier nor adversely affect maintenance by supplier technicians.
4. The modified machine should be able to be operated by both disabled and able-bodied operators.
5. The modified machine should be able to be easily put back to its unmodified state.

## Design

The modifications required to satisfy the goals as set up above vary according to the particular type of electronic industrial sewing machine concerned. Two types of machines from different manufacturers were successfully modified by the Centre. In both cases, a push-button control panel provided machine operations with only one or both hands. The panel was easily accessible so that a hand need not be away from the material at all or for only an acceptable length of time. It is small and positioned in a location which neither interfere with sewing operations nor decrease significantly the amount of space under the machine frame. The electronics used to implement the hands-only conversion plugged into existing connectors on the motor controller so that there was no modification to the existing electronics. This was necessary to preserve supplier warranty and to enable servicing of the machines by supplier technicians without knowledge of the additional electronics. The foot-pedal and knee operated foot-lifter pedal were removed in both cases to allow unrestricted wheelchair access. They can be reinstalled easily and quickly either for maintenance or for operation by an able bodied operator if desired.

The modified machines were described below in the order as encountered by the Centre.

### Juki model DDL-5550-6/SC328

Fig. 1 shows the modified machine. A push-button panel located right next to the thread tension assembly provided the following five functions: STOP, SLOW FORWARD STITCHING, FAST FORWARD STITCHING, REVERSE STITCHING and CUT-THREAD (Fig.2). The hand operated presser-foot lifter that came with the machine was not suitable for production work because it was inconvenient and required much effort to operate (Fig.3). It was replaced with a lever which was shaped for convenient and low force operation (Fig.4, Fig.2).

Conversion to hands-only operation was made simple by a number of input connectors, designated for 'standing' work, provided on the motor controller. There was no technical information provided but it was found that they were activated by relay closure. These functions for standing work were exploited using simple logic circuits to implement the conversion.

PFAFF 465/880M with electric foot-lifter and reverse switch options

The modified machine had a push button panel providing the following seven functions: STOP, SLOW FORWARD STITCHING, FAST FORWARD STITCHING, REVERSE STITCHING, PRESSOR-FOOT UP, PRESSOR-FOOT DOWN (Fig.5)

In this case circuit diagrams of the controller were provided by the local dealer. Motor speed was determined by TTL signals sequenced in a given order. A Motorola MC68705P3 single-chip micro-computer was used to implement the required logic. A micro-computer was not strictly necessary but it was used for convenience and to allow for possible future enhancement at only a slight increase in material cost. The additional electronics plugged into the foot-pedal input of the Pfaff machine.

Evaluation

One Juki and later three Pfaffs were modified and they have been in use in a sheltered workshop for both training and production work since 1989.

The instructors were first apprehensive about a push-button, digital type of control, which was very different from the conventional analog type of control using a foot-pedal. But after trying out the modified Juki machine, they were happy with the push-button controls and immediately saw the benefit of the slow stitching mode for training and for sewing small items in a sheltered workshop environment.

Wheelchair users in the workshop found the machines easy to learn and operate. They did not have a strong preference for the machines with the electric foot-lifter.

A modified machine had been on display in public on numerous occasions. Curious persons who had never operated a sewing machine before can start to sew immediately after a demonstration of how the push-buttons work.

Discussion

A push-button, digital type of control is a plausible way to implement hands-only operation of an electronic industrial sewing machine. The implementation was neither difficult nor expensive in the two cases encountered. The modified machines were found to be suitable for both training and production. It is potentially useful for persons with sufficient motor control for handling the material but not able to operate the standard foot-pedal and knee-pedal confidently.

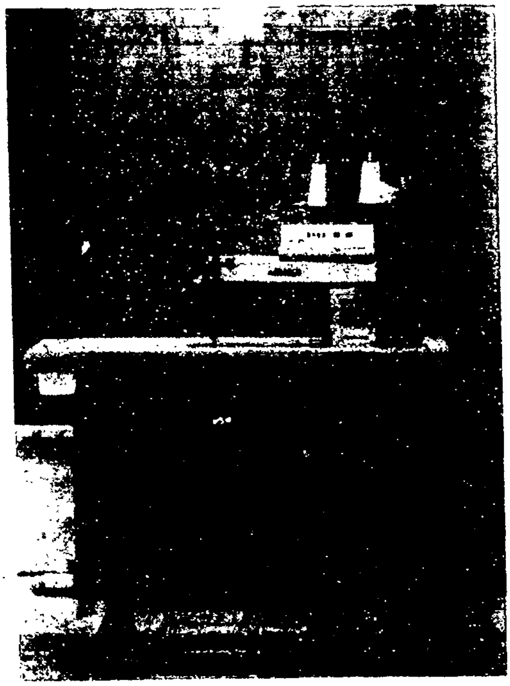


Fig.1 Modified Juki with foot-pedal and knee-pedal removed for unrestricted wheelchair access

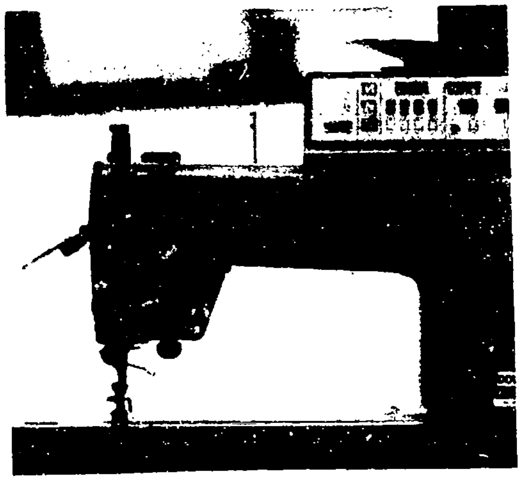


Fig.2 Push-button control panel and new manual pressor lifter of modified Juki


Fig.3 Original Juki manual pressor lifter

Fig.5 Push-button control panel of modified Pfaff


Fig.4 New manual pressor lifter for Juki

Acknowledgements

The technical help from S.C. Siu is greatly appreciated. This work was supported by the Royal Hong Kong Jockey Club

Dominic P.K. Cheng
Rehabilitation Engineering Centre
Hong Kong Polytechnic
Hung Hom
Hong Kong

# CHANGING THE SYSTEM: MEDICAID GUIDELINES FOR AUGMENTATIVE/ ALTERNATIVE COMMUNICATION SYSTEMS IN NEW YORK STATE

Debra J. Zeitlin, MA, CCC - Martin Ferguson-Pell, PhD
Center for Rehabilitation Technology
Helen Hayes Hospital
West Haverstraw, NY

## ABSTRACT

Entitlement to Medicaid funding for augmentative/-alternative communication (AAC) systems is defined by its function as a "prosthetic" device. As such, funding can only be provided to the extent that it meets a specified medical need. The interpretation of "medical need" varies enormously nationwide and even between Local Area Offices of Medicaid within a state. This paper describes a project undertaken jointly by the NYS Office of Health Services Management (OHSM) and Helen Hayes Hospital Center for Rehabilitation Technology. New guidelines were established for the prior approval process for AAC systems which have been adopted by NYS Medicaid. It accepts that AAC systems are required to compensate for a disability that affects vocal communication while ensuring that the evaluation process is conducted by qualified, product independent, speech-language pathologists in a cost responsible and comprehensive fashion.

## INTRODUCTION

Obtaining funding for augmentative/alternative communication systems is always difficult but even more so with the emergence of highly technological communication aids costing several thousand dollars. Few individuals can afford to buy these devices without some financial assistance. Many non-speaking individuals turn to public assistance for funding their needed equipment.

In New York State Medicaid the review of requests for funding of AAC systems has demonstrated differences in interpretation by Area Medical Offices for the definition of "medical need" for the device. Approvals for funding have therefore been inconsistent within the state among the 7 Regional Area Offices. A demonstrable "medical need" is required under federal law for a prescription to qualify for Medicaid funding. In 1988 the NYS Office of Health Systems Management Medicaid Bureau of Standards Development contacted the Helen Hayes Hospital Center for Rehabilitation Technology to ask for assistance in developing guidelines for Medicaid Reviewers to follow in the prior approval process. This paper summarizes the process and the outcome of this collaborative effort.

## BACKGROUND

Throughout the 1980's, grass roots advocacy within the state of N.Y. led to law suits against the Department of Health. This persistent advocacy support by Speech Language Pathologists (SLP) and AAC specialists led the NYS Medicaid Bureau of Standards to review their present philosophy and procedures, and helped NYS develop a realization that revisions to their policies were needed. Their goal was to develop a cost-responsible method of reviewing prescription justifications while broadening the interpretation of "medical need" to embrace the philosophy that an AAC system serves to overcome the disabling effects of communication impairment through the restoration of normal communication.

## METHODS

This project was initiated by a meeting of representatives of NYS OHSM, Speech-Language Pathologists who specialize in AAC, and representatives from Vocational & Educational Services for Individuals with Disabilities (VESID) and NYS Department of Education. The agenda of this meeting was to review existing mechanisms for funding AAC systems through Medicaid. The outcome of the meeting included an approach towards establishing new guidelines through a collaborative effort of the AAC specialists and the Bureau of Standards and Development. A series of working meetings of the AAC specialists ensued and negotiations between members of the CRT and The Bureau Of Standards Development took place over a 2 year period. The Office of the Advocate for the Disabled was provided with information for comment at critical stages in the development of the guidelines.

The second phase of this project included a survey to collect baseline data to obtain information from AAC prescribers on the effectiveness of the Medicaid prior approval process before implementing the new guidelines. There will then be a one year follow-up survey to determine if the new guidelines met their goals of expedited, cost responsible AAC systems funding approval through NYS Medicaid.

## MEDICAID GUIDELINES

The third phase of this project, its implementation, focused on information dissemination. This was accomplished on two fronts. The NYS SLP's were sent a packet of information describing the new guidelines and included the new evaluation protocol. Two one-day training sessions were held for the Medicaid Area Office Personnel to train them in the use of the new guidelines. One of the authors (DZ) was an instructor for part of these training sessions.

## RESULTS

Early this year the Guidelines were completed. The final version included concessions from both the AAC community and the Medicaid Office. The guidelines assist in the definition of candidacy so that "medical need" embraces the concept that "an individual is eligible for an AAC system when their ability to communicate using speech &/or writing is compromised and insufficient for normal conversation". The guidelines include definitions of AAC systems and procedures that can be used consistently statewide for reviewing prescriptions. One policy in the guidelines includes provisions for funded trial periods to demonstrate the suitability of a prescribed system. This policy will fund trial periods but does not mandate them. The rental will be paid by Medicaid from 30 to 90 days. When a trial is recommended a transition plan to purchase will be developed jointly by the local Area Medicaid Office and the prescribing SLP in advance of the trial period to ensure smooth transition from rental to purchase. It is also possible to obtain Medicaid funding to modify/replace an AAC system due to improved technology, or to replace a system due to repair status or loss.

Another outcome of this project was the development of a recommended evaluation protocol to be used by the prescribing Speech-Language Pathologist. The evaluation protocol was developed to ensure that the SLP has systematically addressed all the relevant parameters and presented the information in a easily followed format. This process helps to ensure that the evaluation has been carefully thought through and that all evaluation criteria that pertain to funding are presented to the Medicaid reviewer. The philosophy is not to have the Medicaid Reviewer second-guess the evaluating SLP's clinical decision. The approach ensures that there is evidence of a thoroughly performed evaluation that has considered a wide range of AACS options and selected a system that meets the communication goals of the client in a cost responsible manner.

Part of the prior approval process now includes worksheets that are filled out by the evaluating speech-language pathologist and the Medicaid reviewer. These worksheets are included in the process to ensure the evaluating SLP follows the evaluation protocol and includes all the necessary information in the evaluation report. They also help the Medicaid reviewer find the information in a efficient manner. A peer review process has also been implemented to review prescriptions that exceed a maximum cost ceiling (presently >$8,000).

## DISCUSSION

The implementation of these new NYS AAC guidelines is a big step for the assistive device community. Systematic procedures coupled with fair, consistent review should provide improved access to AAC systems. Redefining Medicaid patients' benefits from narrowly interpreted medical need to achieving their maximum ability to communicate through AAC systems, is a philosophy that hopefully will be endorsed by other states.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Debra J. Zeitlin, MA, CCC
Augmentative Communication Specialist
Helen Hayes Hospital
Center for Rehabilitation Technology
Route 9W
West Haverstraw, NY 10993
(914)947-3000, Ext. 3586

# A Conceptual Model for Developing Augmentative Communication Skills in Individuals with Severe Disabilities

Susan M. Hussey, Albert M. Cook, Sheridan E. Whinnery, Lori Buckpitt and Mary Huntington
Assistive Device Center, California State University
Sacramento, CA 95819-6027

Abstract
This paper describes an approach which systematically encourages independence, control and development of communicative competence in very severely disabled individuals. The intervention approach consists of both assessment and training phases which are continually repeated as the client's skills change. A model and two case examples are presented.

## Background

The individual who can initiate, facilitate and terminate a conversation with ease is said to have communicative competence. We frequently hear about such individuals who were able, within a short period of time, to become effective augmentative communicators once the technology was made available to them. At the other end of the scale, however, is the individual who is severely disabled and is working on attaining the ability to influence someone or something in his or her environment. The purpose of this paper is to present an intervention approach that was developed to encourage independence, control and communicative competence in individuals with severe disabilities. This approach is designed to progress the client along this continuum at his or her pace. Different types of technology are considered at all stages of intervention as an additional modality for the practitioner.

For the purposes of this paper, we define severe disability as: (1) limited motor capability, only single switch control, (2) unknown sensory and cognitive abilities due to assessment limitations, (3) a generally passive nature, (4) non-speaking, unknown communicative skills, responsive rather than expressive behaviors.

## Statement of the Problem

Technology is making it possible for individuals with severe disabilities to have some control over their environment and many of these people are being seen for assistive technology evaluations. Although there is an abundance of literature on providing equipment to less severely disabled individuals, there is very little literature or models on intervention for those with severe disabilities. The questions frequently asked are where to start, how to proceed, what are the treatment goals and outcomes?

## Approach

The goal of this intervention is to use technology to develop interaction skills in disabled clients. Specific objectives are to increase both the quantity and quality of these interactions, as measured by their number and the variety of associated co-occurrences, respectively. An interaction is defined as an event during which the disabled person actively controls an object or communicates with a partner.
Our perspective is clinical. The clients to be described were referred to our client service program, and they were not selected as research subjects. In order to formalize our approach, we consider three primary domains in which the client has and/or needs to develop skills. These domains, are the <u>psycho-social</u>, <u>physical-sensory</u>, and <u>communicative-linguistic</u> domains. These are viewed as being in a circle, and the model represents a cyclical process for developing communication skills in these individuals. It is in contrast to the commonly described sequential model in which communication and motor training are viewed as parallel rather than inter-related aspects of intervention.
Our approach consists of both assessment and training phases which are continually repeated as the client's skills change. In this approach, intervention is considered to be a sequence of developing some physical access, coupling this to a communicative function which results

in a social result. As gains are made in one domain, they facilitate progress the others. The cycle repeats as the social results lead to greater need for more physical ability and more communicative functions to continue social interactions. We use an approach which included both professional staff (OT, SP, RE) and "technology tutors"(graduate students) who made weekly home visits for training.

Implications

Case Study One. Janice is a 13 year old girl who suffered a traumatic brain injury at age 3. She is very passive, has very limited hand/arm use and fair head control. She is responsive to family members, and her major need is for social closeness. Treatment goals are to increase classroom participation, expand communication beyond social closeness, increase motor capability and increase social interaction. Prior to her disability Janice was very cautious, and she would generally observe other children playing rather than join in.

We developed a training program to increase Janice's ability to exercise control over her environment through manipulation of objects and through communication. Janice used a single switch with her right hand, but this skill was largely undeveloped and it was inconsistent. She had an understanding of cause and effect, but was inconsistent in using the switch to obtain a desired effect.

A training program was implemented to increase her reliability and consistency. This program centered around the control of computer programs, appliances and toys. Over the 13 months of training in this phase, Janice demonstrated periods of intense activity during which she clearly showed that she understands the relationship between switch activation and the resulting effect. These periods were generally triggered by novel events, and the repetition of the event over several sessions resulted in decreased activity. During the training period, Janice's ability to move her arms and her attention span both increased significantly. Janice also exerted significant degrees of independence, but it was recognized that single switch scanning would be difficult for Janice.

It was also clear that her head control had improved, and Janice began using a head light, and line drawings attached to a flannel board. This training emphasized Janice gaining communicative competence by using her light to initiate an activity. Initially, she used real objects. For example, she shined her light on a piece of a jig-saw puzzle and the observer responded by placing the piece into the puzzle. We then used enlarged line drawings to request an action. She made choices from four possible items. Next the activities became initial choices that lead to more choices. For example, when she chose the activity of putting make-up on, she would then be given a choice of nail polish, blush or eye shadow.

Janice was also introduced to more abstract language concepts. After making an initial choice of an activity, the activity symbols were removed and symbols for "more" and "stop" were used. By choosing more, the activity would continue and by choosing stop, the activity would stop and the activity symbols would be placed back up so that another choice could be made. As time went on, Janice was able to make use of these concepts. These symbols were also generalized into the card game of blackjack.

Over the 4 months of training in this phase, Janice has demonstrated her understanding of the line drawing representation of an activity. Novel or high interest events elicit the greatest interest. Over a three year period, Janice has moved from being essentially passive to effective communication mediated by the head mounted light.

Case Study Two. Marge is a 23 year old woman with cerebral palsy. She has very limited hand use, gross arm use, limited head control, and unknown cognitive and linguisti skills. Her primary needs are f social closeness, and interaction with family and friends. Treatment goals are to increase motor skills, group home communication, and independent choice making.

A tip switch was attached to her

left wrist and she activated it by lifting her hand and arm. We began training her to activate the switch to obtain interesting results using computer graphics and sound. To make use of the switch to engage in social activities, computer games were used in which Marge played against her mother. She developed skill in activating the switch without time constraints. However, she became bored quickly. Because she can only use a single switch, she needs to use scanning to make choices for communication, and this requires that she activate the switch at a specific time. We tried to develop this skill using computer programs, but this task was not easy for Marge. Once Marge did achieve success with this task, we needed to develop her ability to physically select from an array of several choices. This progression was even more difficult for Marge, and she was unable to succeed at it.

Marge's mother asked that we re-evaluate head control, and that we include voice output in a direct selection mode. Since Marge's head control had improved dramatically during her motor training, we attempted light beam selection using the ACS RealVoice. This has been more successful, and Marge has been able to choose from three options reliably. She continues to be motivated after a period of six months (much longer than any other task have lasted), She is using this system for daily communication.

Discussion

This type of training program may not be appropriate for all severely disabled individuals, and several factors coincided to make this possible in both cases. First of all, a program such as this could not have been carried out without the dedication and interest of the technology tutors who were willing to make frequent visits to the client's home. The technology tutors met on a regular basis with the center staff to discuss the client's progress and make changes in the implementation program. Working with the clients at their home or program sites also seemed to make a difference because the clients were more comfortable and they were able to relax. These factors increased performance and learning. Also, in both situations, funding was available through private trust funds and the family did not have to wage a battle for funding.

Both of the mothers put a priority on their daughters gaining some control and some ability to communicate, but, as dedicated as they were to the process, they wanted to remain the "mother" and not be the therapist or teacher. As clinicians, we often expect the parents of our clients to carry through on a daily program. We don't think how difficult this might be for them, especially in light of their other roles.

Both of these individuals became disinterested in the computer and the software programs. On the other hand, both of them responded well to "social closeness" and were interested in interacting with people and doing age related activities.

Each of these individuals initially used her arm to activate a single switch and now is using a light beam worn on her head. The initial use of the arm may have helped motor learning overall by developing a greater sense of control since neither of these individuals displayed adequate head control prior to the use of switch-based motor training. In fact Marge's mother initially did not want Marge to use her head for control since this had not been successful in the past. Finally, the importance of ongoing evaluation and program planning and perseverance in working towards long term goals cannot be over emphasized. Although breaks in the training occurred naturally as needed by the client and team, after each break everyone was once again energized to work toward the goals.

Susan M. Hussey
Assistive Device Center
California State University
6000 J St.
Sacramento, CA 95819-6027

16.3

# Meeting Multiple Functional Needs with Separate but Equal Interfaces

Albert M. Cook and Susan M. Hussey
Assistive Device Center
California State University
Sacramento, CA 95819-6027

Abstract
This paper describes several cases in which integration of the functions of mobility, communication, computer access and environmental control is less desireable than the use of discrete control interfaces and assistive devices for each function.

Background
A current trend in assistive technology application is the integration of systems for communication, powered mobility, environmental control and computer access (see (1) and (2) for example). The major focus of this integration is the use of the same control interface for several applications.

While we acknowledge the value inherent in the simplification that can result from this type of integration, we believe there are still a large number of situations in which separate but equal control interfaces and devices for each of the functions are not only warranted but highly desireable. In some cases, partial integration (e.g. of computer access and augmentative communication) is useful, even if the other functions are separate. We describe several cases which illustrate these points.

Statement of the Problem
When an individual with a disability has several needs (e.g., mobility, communication, environmental control) and electronic devices are to be used to meet these needs, it is tempting to integrate all of these applications into one system accessed by one control interface. This approach is not always the most useful or effective. There is still a very significant role to be played by discrete devices and control interfaces assembled for specific applications.

Examples of Discrete Systems
Case One. Paula is a 30 year old woman who has quadriplegic spasticity secondary to meningitis at age 10. She is married and lives with her husband and young daughter. Paula was referred for assessment to determine the most appropriate augmentative communication system for her. She has used a single switch row/column scanning communication system. Paula has also used an adapted input device for single switch computer.

Because Paula is able to use a joystick with her left hand to control her powered wheelchair, this was tried in a directed scanning mode for communication. She was able to use this approach, but it required significant effort, and several switches were also evaluated for communication. A dual rocking lever switch was used with her right hand to evaluate the use of Morse code. Paula pressed one side (dots) of this switch with her index finger and one side with her middle finger (dashes). Morse code was easier for her to use than directed scan with the joystick, and she preferred it for communication. Thus, even though Paula was very accomplished at controlling her wheelchair using the joystick, this control interface was not the one of choice for communication.

Case Two. Joyce is 39. She has cerebral palsy, and she currently lives with her parents. She is non-verbal and uses a communication device synthesized speech.

Joyce's goal is to be in an independent living situation. She was referred to look at areas in which assistive technologies could assist her: communication, powered mobility and environmental control.

Joyce currently uses a tread switch mounted near her knee to control her scanning communication device. She is very effective with this switch, and attempts to use other control sites (e.g., head pointing) were less successful. The switch controls a scanning software program (Words+) running on a laptop computer.

The communication and environmental control aspects of Joyce's system were integrated by using a remote interface (Serial Relax) connected to the laptop computer. The Relax is activated by the scanning communication software computer program, and it controls a TV, VCR, appliances and an automatic telephone dialer.

For powered mobility, Joyce had been using a set of four tread switches (one for each direction) mounted on a foot plate. This was difficult for her, and as an alternative, a lever switch was placed on each side of her head for steering, with the forward and reverse switches left on her foot plate. Joyce was able to control these easily, and she preferred them to the foot switches for turning.

Joyce also needed to activate a call system for emergency help over the telephone. This was addressed by acquiring an alarm system which is tied into a 24 hour surveillance company. This system required a single switch for activation. She was able to consistently activate a wobble or tread switch with her left arm, and it was decided to use this site for the emergency call system.

This provided an advantage since her control over her arm was less limited by being supine in bed than was her control of her knee. Also, when she was seated in her wheelchair, arm use did not interfere with either her powered mobility or her communication since they used other control sites. Two tread switches were mounted near the head of the bed to be used by Joyce to access the emergency call system while in bed. A wobble switch with a quick release mounting on both her powered and manual wheelchairs was also installed for emergency calling while she was in either wheelchair.

Case Three. Eileen is a 62 year old woman who suffered a brainstem stroke. She now requires maximum assistance for daily living. Her major form of mobility is a manual wheelchair which she is can tolerate for approximately four hours at a time, and she remains in a reclining type chair at home while watching television. At the time of referral, Eileen's communication consisted of words, facial expressions, yes/no responses, and inflectional vocalizations. She indicated her needs and choices by using an eyegaze letter board.

Eileen is able to use head movement to make selections using a light pointer (Adaptive Communication Systems) mounted on a headband on the left side of her head. Using the light pointer with the Real Voice (ACS), she is able to quickly make selections and control the device.

Eileen also expressed a desire for a simple environmental control unit (ECU) which will control the TV. Eileen enjoys watching tv and she wishes to be able to turn it on, select channels, and control volume her self. With a single switch mounted near her head, she can use an ECU. We initially decided to use an optical switch which she could activate using the communication system light beam. However, the optical switch had several limitations. First, it was an active switch, and this required that batteries be replaced relatively frequently since the switch needed to be turned on at all times for Eileen's call alarm. It was also difficult to place the optical switch in a location which prevented accidental activation by ambient room light. For these, and other reasons, we decided to use a wobble switch mounted to the back of her reclining chair for environmental control (including the call function). Since she spends the majority of her time in this chair, she has access to the call system all the time. Also, she can access the switch with her head while the light pointer is on her head.

Case Four. Dorothy is a 45 year old woman with amyotrophic lateral sclerosis. She lives with her son, daughter, and husband and receives attendant care daily. She uses a powered wheelchair, with a joystick control.

Dorothy was referred for computer access for written communication, and ECU. She would like to be able to write personal correspondence and do bookkeeping for the family business. The Zygo touch switch was the easiest to activate of several interfaces tried. A trackball was used with the Freewheel virtual keyboard software for text entry, and she was able to move the cursor using the trackball. A Tash mini joystick, was also tried, but she preferred the trackball for text entry. Since Dorothy cannot press the buttons on the trackball, a modification was made to allow the touch switch to be substituted for the standard button.

Television and appliance control were implemented using a stand alone ECU (The Relax controller) accessed using a single touch switch. This approach was taken, rather than integrating the communication and environmental control functions because Dorothy will generally not need access to the television or appliances while she is writing.This unit has a touch switch permanently attached so it is ready whenever Dorothy requires it, and it differs from Joyce's case mainly because Joyce also uses her communication system for augmentation of her speech, and she needs to have access to it at all times.

Automatic telephone dialing was accomplished by a device which uses a separate single switch input, rather than integrating it with the other ECU functions. This is primarily because the touch switch can be held by Dorothy, and the telephone is not in the same physical location as the television. Since Dorothy's current needs for controlling lights is restricted to four or fewer, a simple combined unit which dials the telephone and controls four appliances (Tash Unidialer) was recommended. A separate switch was obtained to be connected to this unit at all times.

Control of an electric bed is possible with a modified unit which also requires single switch input and uses scanning like the Relax and dialer do. Since Dorothy will be using this unit only in bed, a dedicated unit with its own single was acquired.

## Discussion

These cases illustrate several general points. First, it is not wise to assume that integration of controls and/or functions is always desireable. There are many cases in which separate controls and/or devices actually provide greater flexibility and utility than an integrated system. Second, integration of functions or controls need not be "all or none". In some cases (such as case 2) some subset of functions are most appropriately integrated (in this case communication and ECU) while others (mobility and emergency call) remain separate. Third, the client's preference also needs to be considered. A preference for separate interfaces may make it easier for the client to switch between activities.

As illustrated by cases one and four, the effective use of a particular control interface for one function (a joystick for mobility) is not necessarily an indicator that this same interface should be used for a different function (communication). Often the separation of functions and control also makes use of different anatomic sites (e.g., cases 1 and 2). Alternatively, the same anatomic site (head-case 3, hand-case 4) may be used, but with different control interfaces (case 3) or functions (case 3 and 4).

In summary, the most important consideration is that integration of functions, control interfaces and anatomic control sites must be carefully considered in each specific case, with the major emphasis placed on the functional outcome for the client in each of the performance areas to be assisted.

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Albert M. Cook, Ph.D.
Assistive Device Center
California State University
6000 Jay Street
Sacramento, CA 95819

# A Framework for Characterizing AAC Device Learning for Persons with Mental Retardation

Cynthia J. Cress
Greta J. French
Trace R&D Center
University of Wisconsin-Madison
Madison, WI

**Abstract**

Practical considerations limit the amount of information that is feasible to gather when assessing a client's skill with an AAC device. This article suggests a framework for collecting the kinds of performance data which reflect crucial learning skills for persons with mental retardation. Learnability of a given device for an individual is best expressed as a function of procedural knowledge/ability, learning, maintenance, and generalization. Several examples of such device performance profiles for children with mental retardation are included to demonstrate the different skill estimates gathered from each source of information.

**Background**

The measurement of learning in persons with mental retardation depends on theories of what constitutes learning and how underlying skills may differ with cognitive disabilities. While the acquisition of knowledge is an important component of learning, current theories dispute that learning can be accurately measured by a unitary estimate such as the static problem-solving skills measured by Spearman (1927). Indeed, responsiveness to training is considered a primary component of intelligence, since it measures not only what a student has learned within a particular domain and situation, but what he/she is capable of learning across task domains (Budoff, 1974; Vygotsky, 1978).

For persons with mental retardation, these skills in active problem solving are proposed to be the primary source of learning difficulties, resulting from a general slowness or incoordination of executive control functions which dictate the selection, maintenance, and use of other cognitive skills (Campione, Brown, & Ferrara, 1983). Specific learning difficulties in mental retardation that are related to these problems in managing cognitive skills include the maintenance and transfer of learning. Campione & Brown (1978) demonstrated that children with mental retardation were less likely than cognitive-age-matched peers to spontaneously employ strategies, even when they were taught and demonstrated the ability to do so. These authors claim that spontaneous transfer of information rarely happens in persons with mental retardation, and that failure to generalize information is part of the definition of mental retardation.

With nondisabled populations, learning is typically characterized by a criterion-related measure. For instance, in the measurement of computer learning, research studies report criteria of speed and accuracy to demonstrate satisfactory learning of given computer tasks (e.g., Haller, Mutschler, & Voss, 1985). Maintenance and generalization of skills are often presumed to follow directly from successful learning, and individual variation in skills are typically attributed to differences in factors such as computer experience (English, Engelbart & Berman, 1967) or response to task-related cognitive loads (Karat, McDonald, & Anderson, 1985).

**Statement of the Problem**

When evaluating AAC device performance, for either researc. or clinical purposes, information gathered is often limited to a person's existing skills with a given device. For instance, speed, accuracy, and overall success may be sampled and compared across tasks and devices. Since data collection time is limited in an evaluation setting, it is necessary to extrapolate from these short-term estimates to predictions of long-term success with a device.

Information about static skills (current knowledge and abilities), however, is a poor predictor of the ability to learn a new skill (Budoff, 1974; Vygotsky, 1978). In studies of computer learning, static measures such as speed and accuracy were poor predictors of performance in young children acquiring necessary device control skills (Cress, French, & Tew, 1991). For children with mental retardation, who are more liable to have increased difficulty in maintaining and applying new control skills, it is increasingly important to sample dynamic as well as static performance skills. By sampling only static skills, we know only what a person already knows, rather than what they may be able to learn over time. A more complex assessment framework is needed which includes estimates of learnability as well as range of performance with communication or computer devices.

**Approach**

The following is a proposed framework for sampling relevant components of learning behavior for persons with mental retardation within an AAC device evaluation. While complete assessment of any of these factors is impractical for most clinical settings, Table 1 indicates the kinds of data that are possible to gather during a single 30 minute session with unfamiliar devices, in the following categories:

1. *Knowledge/Abilities*: These are static samples of behavior with little or no intervention from the assessor, indicating the impact of a client's current procedural and cognitive skills, as well as past experience, on device use. Since the goal of most evaluation sessions is to predict future learning, it is necessary to sample learning potential as well as current skill levels.

2. *Learning*: This step involves providing unfamiliar or incompletely learned tasks and comparing the amount and levels of training necessary with the skill level achievable by the client. The amount of facilitation necessary to demonstrate improvement with a device is a

viable measure of the learnability of that device (Vygotsky, 1978), even if the client is unable to achieve independent competence with the device during the evaluation setting.

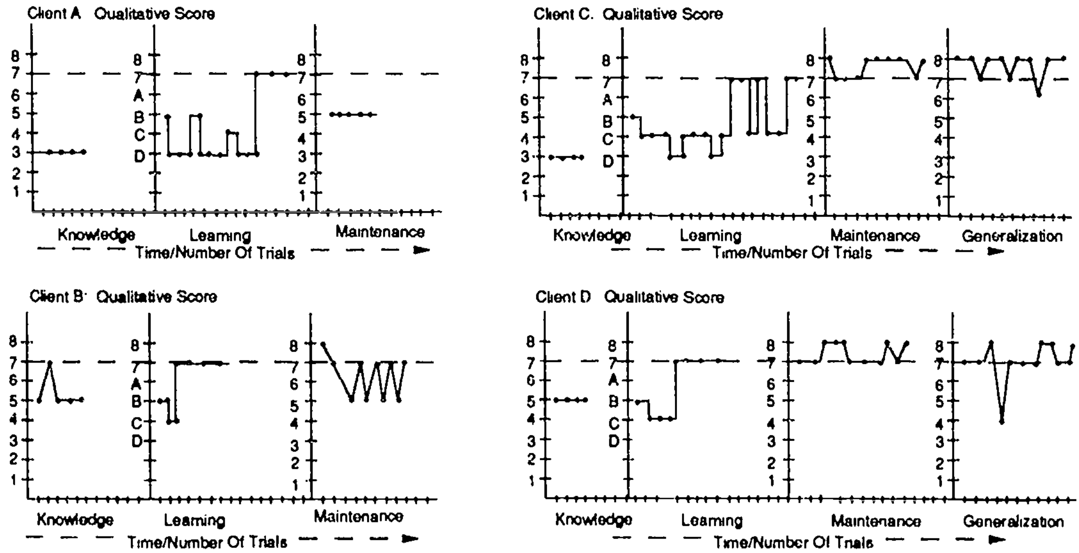
3. *Maintenance*: In addition to potential for learning a new skill, it is particularly important to estimate how well a child with mental retardation can maintain new skills once learned. Children with mental retardation do not necessarily continue to apply the skills that they have learned even within the same task and context (Campione & Brown, 1978). Maintenance estimates can be obtained by repeating standard ability assessments without intervention to test consistency of learning, or by sampling performance periodically during other unrelated tasks.

4. *Generalization*: Since device learning must eventually be applied to different tasks and settings than those used in an evaluation session, it is necessary to gather information that predicts generalization of skills. In a limited timeframe, it is possible to sample this by testing performance across tasks and settings. In addition, predictions of generalizability of device skills may be supplemented by information on more general cognitive skills of the user and requirements of different devices. Some evidence suggests that successful maintenance and generalization of computer interface learning depends in part on the degree of discrepancy between a client's current cognitive and procedural skills and requirements of the task or device. For instance, some theories propose that all children with mental retardation require specific training cues directed at generalization (self-directed training) in order to learn any new task, regardless of difficulty (Campione, Brown, & Ferrara, 1983). However, in the current study, children who were close to the threshold of competence necessary to successfully and independently operate a given device required little or none of these self-directed cues, while children further from this threshold were more likely to require this type of training. Thus, based on estimates of cognitive and procedural skill requirements of various AAC devices, it would be possible to compare the learnability of one device used in an evaluation to several other devices without extensive testing.

Table 1 provides four examples of the performance profiles that can result from this kind of analysis. Subjects were children with mental retardation (M.A. 2.7 - 4.2) who were learning the operation of standard computer interfaces in moving objects on a computer screen. Graphs A-D are profiles for four different children of knowledge/ability, learning, maintenance, and generalization of skills with a single interface (mouse, trackball, touchscreen, or keyboard). Since decisions to continue with a particular activity were based on a minimum standard of success (quality scores at or above 7 for 7/10 assessment or 3/10 training trials), not all sampling sessions are the same length. The graphs for training cues represent order rather than absolute level of training cues provided; each level of training A through D provides successively more support to the learner and is further from independent use of the device (indicated by a score of 7 or 8). Only clients who passed earlier levels were tested for further tasks (e.g., clients who did not maintain skills were not expected to generalize these skills to more cognitively challenging tasks).

For all of these clients, initial testing of abilities was a poor indicator of eventual success in learning these

**Table 1: Performance Profiles for Computer Learning by Children with Mental Retardation**



controls. All of these profiles show that the clients could not use the test devices at the beginning of the session, even though they were given the kind of demonstration and practice opportunity that are sufficient for adult-like learning of these controls. Also, all of the clients passed minimum learning requirements for demonstrating educability for independent use of these devices (reaching the threshold of competence). However, performance in maintenance and generalization tasks varied across subjects in ways not predicted by entry or post-training levels of performance. Client A did not continue to apply the successful techniques demonstrated in training, and quickly lost the necessary task behaviors. Client B had limited success in ability sampling on which to base further training, but showed insufficient maintenance to test generalization at his current levels of skill. While Clients C and D demonstrated similar maintenance and generalization of skills, Client D showed slightly greater educability because fewer and less specific training cues were required to achieve independent success. The extent to which this relatively small difference in skill predicts long-term changes in generalizability is not evident from these samples.

**Implications and Discussion**

Thus, none of these types of information are an adequate picture of performance potential in isolation, but together they provide the potential for estimating device learning within a limited session. In many clinical assessment or therapeutic settings, there would be chances for a more thorough and representative sampling of each type of information than was available within this research study. However, even these brief samples are more accurate predictors of device learning than speed/accuracy samples or cognitive age estimates alone (Cress, French, & Tew, 1991).

The components of this assessment framework are derived from both theory and practical experience. Researchers and clinicians will already include several elements of these performance factors in evaluation settings, either formally or informally. This article provides a mechanism for systematically planning and assessing types of information most informative about device performance.

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Cynthia Cress
Trace R&D Center
S-151 Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280

16.5

# AN EVALUATION OF REDUCED KEYBOARD TYPING BY CEREBRAL PALSIED ADULTS

John L. Arnott, Muhammad Y. Javed & Bernadette Brophy
Dept. of Mathematics & Computer Science
University of Dundee
Dundee, Scotland, United Kingdom.

## ABSTRACT

Reduced keyboard and automatic character disambiguation techniques have been used with four cerebral palsied typists. The performance of the typists was monitored over a period of use of the reduced keyboard, on which each key represented more than one alphabetic character. The typing method was found to be easy to use and it reduced keying errors made by the typists.

## BACKGROUND ON REDUCED TYPING KEYBOARDS

### Reduced Typing Keyboards

Reduced typing keyboards are intended for use by physically disabled persons who need special switch or keyboard systems with a limited number of keys or switches. They therefore contain fewer than 26 keys for alphabetic characters, with several characters allocated to each key. An automatic disambiguation process can be used to identify the character implied by any key press (1,2,3,5,6,7,9,10). This process reduces the number of switch activations required to select any alphabetic character, in order to reduce the physical effort needed for typing text on the reduced keyboard.

### Character Disambiguation

A typical reduced keyboard and disambiguation system operates as follows. The user of the reduced keyboard presses the appropriate key for a desired character, and the automatic disambiguation process uses known statistics of character sequences in the relevant language to predict which character is intended. The user can accept this predicted character (by pressing the key for the next desired character) or reject it by pressing an "Error" key, which makes the disambiguation system predict the next most probable alternative character for the pressed key. The user presses "Error" until the system predicts the correct character. No more than two presses of the "Error" key will be needed to select any character if there are three alphabetic characters on each key. The ideal keying efficiency which this type of system can achieve is 1, i.e. 1 character selected for every key pressed, but this is not likely to be achieved in practice because of imperfect disambiguation. Keying efficiencies of up to 1.025 keys per character (97.52%) have previously been achieved (4) in simulation experiments with an adaptive disambiguation system.

### N-gram Based Disambiguation Models

The principal method of character disambiguation for a reduced keyboard relies on a prediction model built from n-grams (strings of characters from conventional text) to estimate, on the basis of the immediately preceding typed characters, which one of the characters on a pressed key is the most probable in the prevailing context. The disambiguation system offers that character to the user, who either accepts it, or rejects it using the "Error" key. N-grams can be of any length n; monograms (n=1) consist of single characters, bi-grams (n=2) consist of two (e.g. "tr", "oo") and tri-grams (n=3) consist of three (e.g. "tre", "ook"). N-gram models can be constructed from samples of existing text, or, in an adaptive system, from the typed text of the user of the reduced keyboard.

## RESEARCH: DISAMBIGUATION FOR DISABLED USERS

The purpose of the work reported here was to investigate whether members of a target client group could use such a disambiguation system in a typing task. Some features of the technique were unconventional, such as the multi-character keys and the use of the "Error" key to elicit alternative predictions from the system. Other research had shown that able-bodied users could use a reduced keyboard (6,8); it was therefore important to investigate whether potential disabled users could assimilate the typing technique and use it effectively. The users in this case were a group of cerebral palsied adults (three male (DB, EM & IW) and one female (MM)) who all had experience of using the conventional QWERTY typing keyboard as their principal writing tool, but who suffered low typing speeds and high error rates as a result of their physical disabilities. Reducing the number of keys (or switches) and increasing the spacing between the keys was seen as a possible way of making typing easier and reducing error rates for these users.

## METHOD

### Input Device

The most appropriate input device for all of the four users was found to be the normal computer keyboard, because they were used to operating it (although slowly and with frequent errors) and because other methods (e.g. membrane keyboards) did not have the correct tactile or motion characteristics to match their abilities. (One user could not exert sufficient downward pressure on the membrane switch surface to ensure switch activation, for example, whereas another could not target switch areas accurately on the smooth surface.) All of the users preferred to use the conventional computer keyboard (with which they were familiar) as their input device.

### Reduced Keyboard Layout

The computer keyboard was therefore programmed as a reduced keyboard, with twelve of the keys allocated as active typing keys, and the other keys disabled so that there was a "dead zone" around each active key. This "dead zone" assisted in reducing the mis-keying errors caused by the user striking keys neighbouring the real target key. A key-allocation program was developed to assist in the definition of the layout of active keys and the characters they represented. Layouts could be tailored to suit individual users. The character groupings were based on a modified version of the "TOC" keyboard (2) because this keyboard had previously been found to give good keying efficiency (1). No more than three characters were allocated to each key in this layout, in the following groups: (ABX); (DEF); (GHI); (OKL); (MNJ); (PQR); (SU Period); (VWC); (YZT); (Space Comma). The key allocation program enabled these groups to be assigned to particular keys on the computer keyboard, so that a 12-key layout could be mapped easily onto the existing keyboard.

### Word Processor for Reduced Keyboard

A simple computer-based word-processor was created for use with the reduced keyboard. A window for the predicted character was positioned in the bottom right-hand corner of the computer display, where it could be easily located and viewed by the user. The predicted character was displayed in this window in much enlarged form in order to assist recognition by the user, and it could also be output in synthetic speech to further assist recognition. The user could therefore easily monitor the output of the disambiguation system and decide whether to accept or reject the character. A second window contained a diagram of key groupings on the reduced keyboard for user reference. All text typed by the user appeared in a text window at the top of the display.

### Text Samples for Typing Evaluation

Text samples were selected from a text corpus such that all samples had very similar characteristics, such as overall length (167-169 characters), mean word length (6.46-6.76 characters) and type/token ratio (0.84-0.96). An adaptive disambiguation model was built from the corpus to give representative performance throughout the evaluation. The subjects typed the text samples in evaluation sessions spanning a period of five weeks.

## RESULTS: TYPING RATES AND KEYING EFFICIENCY

### Typing Rates

Table 1 shows the text entry rates achieved by the subjects in producing error-free text on the reduced layout over the five-week evaluation period (cols. 1-5), and on the conventional QWERTY layout (col. Q).

| Sub jct | Evaluation Week 1 | 2 | 3 | 4 | 5 | Qwert Q |
|---|---|---|---|---|---|---|
| DB | 7.00 | 8.11 | 9.52 | 10.30 | 12.70 | 12.82 |
| EM | 6.26 | 7.48 | 10.91 | 13.75 | 15.34 | 16.04 |
| IW | 6.71 | 8.94 | 13.21 | 15.62 | 16.66 | 34.68 |
| MM | 7.24 | 8.46 | 11.18 | 12.98 | 14.34 | 14.89 |

**Table 1. Text Entry Rate (Character/Minute) for 4 Subjects using Reduced Layout over a 5 Week Period (1-5), and QWERTY Layout (Q).**

At the end of the evaluation period, three of the users were able to produce correct text on the reduced layout as quickly as they could on the conventional QWERTY layout (with which they were very familiar) indicating that the reduced layout with disambiguation was a viable alternative input method for them. One of the users was relatively good as a QWERTY typist, however, being approximately twice as fast as the other three, but attained rates on the reduced layout similar to those of the other three. The users approximately doubled their output rates on the reduced layout over the evaluation period, and as rate was still increasing at the end of this period, further improvement may well have been possible.

### Keying Efficiency

| Keying Effic. | Subject DB | EM | IW | MM |
|---|---|---|---|---|
| Best | 1.048 | 1.048 | 1.054 | 1.054 |
| Mean | 1.079 | 1.076 | 1.081 | 1.074 |
| Worst | 1.108 | 1.118 | 1.120 | 1.125 |

**Table 2. Keying Efficiency (Keys/Character) achieved by Subjects over five-week period.**

Table 2 shows the mean and range of keying efficiency achieved by each subject. Keying efficiency is defined as the number of keypushes required to type a text divided by the number of characters in that text.

Previous simulations (4) using a similar disambiguation system have shown that keying efficiencies in the region of 1.025 to 1.074 keys/character can be achieved depending on the text sample used. The keying efficiencies achieved here are comparable with these figures, and demonstrate that the reduced keyboard technique can be used efficiently by cerebral palsied users.

Typing Errors
The users generally made more keying errors when using the conventional QWERTY layout (computer keyboard) than they did on the reduced layout, because key(s) neighbouring the target key were struck in error. One user (MM) pressed the "backspace" key 59 times when typing a 168-character text sample on the conventional QWERTY layout, but used the "Error" key only 24 times when typing the same text on the reduced 12-key layout. The "dead-zones" around each target key on the 12-key layout were therefore very effective in reducing the amount of error correction required of the users.

Questionnaire
The users responded positively in a questionnaire about the reduced keyboard technique, indicating that it was relatively easy to use and that it improved their typing compared to the QWERTY layout.

## CONCLUSIONS

The four cerebral palsied users found the reduced keyboard technique to be an effective and efficient way of typing text. They made fewer keying errors, and three of the four users could type text as rapidly using the reduced keyboard as they could with the conventional QWERTY keyboard. The technique made the conventional computer keyboard more accessible and usable for the four users without the addition of any physical or mechanical accessories or aids. It can be concluded that the reduced keyboard technique is an effective method by which physically disabled persons can type text, and that it can enhance writing and computer access for such users.

## ACKNOWLEDGEMENTS

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Dept. of Mathematics & Computer Science,
The University of Dundee, Dundee DD1 4HN,
Tayside, Scotland, United Kingdom.

# Learning and Performance in Scanning Systems with and without Word Prediction – report on a pilot study

Heidi M. Horstmann, M.S. and Simon P. Levine, Ph.D.

Rehabilitation Engineering Program
Department of Physical Medicine and Rehabilitation
University of Michigan

Abstract
A pilot study has been performed to begin to examine how the cognitive and perceptual loads introduced by a word prediction feature impact learning and performance. Two pairs of able-bodied subjects transcribed text using two row-column scanning systems for ten consecutive sessions each. The two systems differed only in that one system had a word prediction feature, and subject pairs differed in their order of system use. The results, while limited in their statistical power, suggest that the training and prior experience provided to a user may be a factor in determining when word prediction helps and when it hinders.

## Background

Designing an assistive technology system to improve physical efficiency may also place increased cognitive and perceptual requirements on the user, leading to unknown effects on the user's ability to learn and use the system. This dilemma has been discussed most frequently in connection with augmentative communication (AAC) systems, especially those that employ a word prediction feature (1,6). Word prediction systems are successful in reducing the motor requirements for text entry; however, comparisons of text entry speeds with and without word prediction show that while some users enjoy substantial improvement, others may improve only marginally or even decrease in speed (4).

## Research Questions

Our goal is to determine the general principles underlying the interaction between a user and a word prediction system, in order to gain a deeper understanding of the trade-off between the increased cognitive/perceptual requirements and decreased motoric loads. We aim to use these principles as the basis for mathematical modeling to simulate the effect that different user and system characteristics, as well as different intervention strategies, have on overall performance (2). As one of the early steps in this process, we have designed and performed a pilot study, to begin to look at how the cognitive and perceptual loads introduced by a word prediction feature impact learning and performance.

## Method

I. Subjects. Four able-bodied subjects were used. No subject had prior experience with the systems studied.

II. Interfaces. The two interfaces under study used single switch row-column scanning as the basic selection method. The first interface, referred to as "Letters-only", required letter-by-letter spelling, using a fixed frequency-based letter matrix. The second, referred to as "Letters+WP", used the same letter matrix augmented by a word prediction feature. Characteristics of the word prediction feature included: (1) a six-word list, presented vertically to the right of the letter matrix; (2) fixed prediction dictionary, containing 82% of the words to be entered; (3) fixed order of words in the list; and (4) "half-and-half" scanning pattern, where the system first scanned between the entire matrix and the word list, then scanned the items in one of these halves based on the user's selection. Both systems included adjustable timing parameters: the scan rate, an extra delay for first row and column in matrix and first word in list, and an extra delay on the matrix half (for the word prediction system only).

III. Experimental Design. Subjects were divided into two pairs, Pair A and Pair B. For Pair A, the order of system use was as follows: (1) training for Letters-only; (2) testing with Letters-only; (3) training for Letters+WP; (4) testing with Letters+WP. For Pair B, the order of system use was reversed: (1) training for Letters+WP; (2) testing with Letters+WP; (3) training for Letters-only; (4) testing with Letters-only.

Training combined verbal instruction and practice. Subjects were given the following goal: to achieve their maximum possible rate with each interface while keeping to less than 10% missed selections (i.e., item was correct but not selected at first opportunity) and less than 5% incorrect selections (i.e., both corrected and uncorrected errors). During Letters+WP training, the rationale behind word prediction was explained, but subjects were not given specific guidelines for when to use the feature. Subjects practiced using the system on a text sample, until they could select text with 95% accuracy.

Testing sessions involved a sentence transcription task, performed twice a week, in which subjects transcribed two five-sentence blocks of text, separated by a five-minute rest period. A two-minute warm-up period before beginning each block was provided. Subjects were allowed to adjust system timing parameters either before or after the warm-up period, but not during the five-sentence block of text entry. Timing parameters could be adjusted in increments of 25, 50, or 75 msecs.

Text blocks were drawn from published typing tests (3) and matched with respect to syllable intensity, average word length, percent of "high-frequency" words, overall length, and average scan steps. Subjects read the sentences from index cards, one sentence per card. They had twenty seconds to flip to a card and read the sentence. During this period, no selections could be made. Scanning resumed automatically at the end of the "freeze" period, and subjects then transcribed the sentence using the assigned interface. The sentence card remained in view for reference throughout transcription.

IV. Data Collection. All items selected by subjects were timed, collected, and stored in real-time by software we developed for that purpose. The set-up parameters used during a session were also recorded with the item data. Observations of subject behavior during each session were recorded by the experimenter.

## Results

This pilot work is part of an ongoing effort to collect empirical data that supports the development and validation of mathematical models of user performance. However, in the process of analyzing the data from our first subjects, we have seen some interesting results regarding differences in what was learned by each of the two subject pairs, and these will be the focus here.

For the first ten blocks, subjects who began with Letters+WP (Pair B) entered text more slowly and improved less overall than those who began with Letters-only (Pair A). While the Pair B subjects made an average of 31.6% fewer selections than Pair A, their text entry speed at each of the ten blocks was an average of 18.6% slower, as seen in the left half of Figure 1. Additionally, Pair B's rate improved an average of 28.5% over the first ten blocks, while Pair A improved their rate by 41.6%.

Analysis of the second ten blocks reveals a different trend. Subjects who finished with Letters+WP (Pair A) made an average of 3€.2% fewer selections and had a text entry rate that was an average of 16.0% faster than those who finished with Letters-only (Pair B), as seen in the right half of Figure 1. The improvement of each pair over the ten blocks was basically the same, at 33.2% for Pair A and 35.5% for Pair B.

In the search for what might account for these results, we analyzed how the experience each pair gained in the first half might have affected their performance in the second half. Learning transfer was calculated using the following formula:

$$\% \text{ transfer} = \frac{R_{lrn(1)} - R_{tran(1)}}{R_{lrn(1)} - R_{lrn(10)}} * 100$$

where $R_{lrn(1)}$ is the rate for the first block with the first-learned system, $R_{lrn(10)}$ is the rate for the tenth block with the first-learned system, and $R_{tran(1)}$ is the rate for the first block after switching systems (5). A learning transfer of 100%, for example, means that the subject's text entry rate was not affected at all by switching systems. When subjects switched to a new system after ten blocks, Pair A had a higher amount of learning transfer in moving from Letters-only to Letters+WP than Pair B did in moving from Letters+WP to Letters-only (61.2% vs. 44.8%).

A second set of analyses on the effects of prior experience compared the pairs' performances when they used the *same* system. When Pair A subjects switched to Letters+WP, their performance with that system was an average of 32% faster than that of Pair B (Figure 2). However, when Pair B subjects switched to Letters-only, their performance was no better than that of Pair A (Figure 3). Pair B's experience with Letters+WP gave them little if any advantage in using Letters-only, even though the matrix used in both systems was exactly the same. In contrast, Pair A's experience with Letters-only gave them a definite advantage over Pair B in using the Letters+WP system.

Unpaired two-tailed t-tests were performed for each difference reported above. P-values ranged from 0.02 to 0.87, with the majority falling under 0.25.

## Discussion

A definitive interpretation of these results is difficult, given the small size of the subject groups and other methodological limitations to be discussed below. Nonetheless, the results are intriguing, and a careful consideration of their implications seems warranted to guide a search for relevant evidence in clinical or laboratory reports and to inform the design of future research efforts.

Neither of the systems enjoyed a clear speed advantage over the other, even though both pairs made about 35% fewer selections with Letters+WP. The different order of interface use for each pair may account for this result. When subjects used the word prediction system without any prior experience (Pair B), they were faced with quite a daunting task: to use the switch properly to select either a matrix or a word list item; to visually search for and memorize the matrix locations of 27 characters, while at the same time trying to search the word list; and to develop efficient methods of deciding which type of item to select next, within the time constraints provided by the system. The cognitive time and energy spent in wrestling with these component tasks simultaneously may be a reason why the novice Letters+WP users in Pair B could not keep up with the novice Letters-only users, at least over the ten blocks tested.

The available data suggests that Pair B bore a heavier cognitive burden than Pair A. Despite ten blocks worth of experience with the letter matrix (during use of the Letters+WP system), Pair B subjects do not appear to have learned its layout particularly well. This is based on their relatively low learning transfer score, as well as the fact that their speed on the letters-only system was barely distinguishable from that of subjects who had had no prior experience with the matrix. It may be that trying to learn so many things at once hindered their ability to learn any one thing very well. Additionally, experimenter observations during Pair B's Letters+WP sessions noted that both subjects displayed inconsistent strategies for using the word list as well as mild symptoms of frustration. Data collection at finer levels of detail is planned in order to explore this further.

In contrast, Pair A subjects were able to become proficient at an important component skill, specifically row-column letter scanning, before using the word prediction system. They could focus on learning skills specific to the word prediction feature itself, such as developing efficient strategies of word list search and using them consistently. Our observational data supports this hypothesis, as Pair A subjects seemed to be much more relaxed and consistent in their word prediction behavior than Pair B subjects were. A greater understanding of the word prediction strategies that subjects in both pairs used is needed to pursue this further.

One implication of these results is the following hypothesis: training individuals in component skills may lead to better success with a complex system. No doubt there are clinicians who follow this strategy in their interventions. In our experience, however, this type of intervention is most often used when individuals are having difficulty gaining simple competency in the complex skill, or are improving very slowly. Based on these criteria, neither of the subjects in Pair B would be identified for "remediation" in row-column letter scanning, although both may have benefited from it. To examine this hypothesis further, it would be necessary to have an additional group of subjects who used only the Letters+WP system throughout the experiment.

A full understanding of how user, system, and intervention characteristics combine to influence user performance with word prediction and other AAC systems will require a large amount of empirical study using a variety of methodologies. Our hope is that generalities can be discovered and that similar combinations of factors will prove to have similar and predictable effects on performance. These conditions must be true in order to build model simulations that will predict the effects of novel combinations of factors.

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**Address**
Heidi M. Horstmann
Rehabilitation Engineering Program
1C335 University of Michigan Hospital
Ann Arbor, Michigan 48109-0032, USA

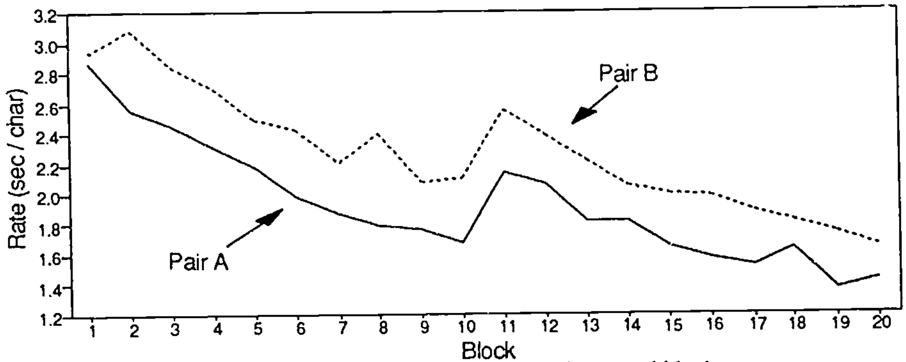

Fig. 1. Text entry rate for each pair over all blocks.

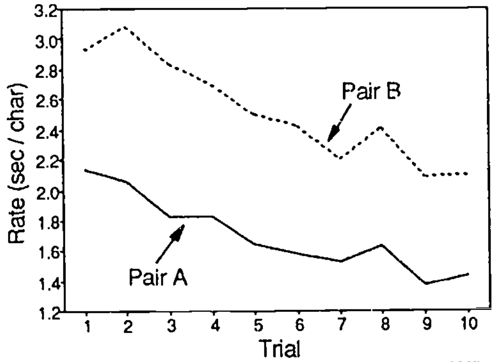

Fig. 2. Rate for each pair when using Letters+WP

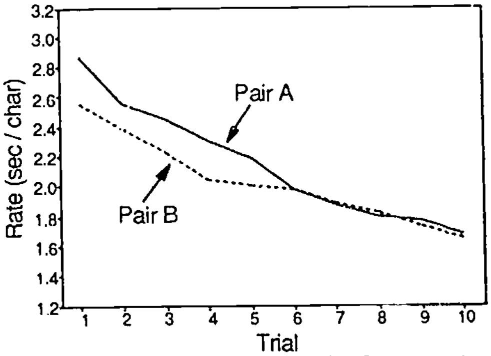

Fig. 3. Rate for each pair when using Letters-only

17.1

# A PROPORTIONAL HAND SPLINT CONTROL

Mark I. Bresler MBME
O'Donoghue Rehabilitation Institute
Oklahoma City, Oklahoma USA


## ABSTRACT

A proportional control that imitates a joystick has been developed. Custom hand splints incorporating an open ended box or "tunnel" for the ring and little fingers enclose photosensors to read finger position.


## STATEMENT OF THE PROBLEM

Several developers have designed body mounted directional controls for users with limited function. These individuals have more control than required by simple switches, but less than necessary for a standard joystick. In 1982 Snell (1) described a thumb mounted thimble inside a ring with metal contacts. Touching the thimble to the ring provided single speed directional control.

## BACKGROUND

As the Tamara System (2) for mobility, communication and environmental control evolves, features are added to ease setup and use. The control input system is a good example. The intended user has control of fingers on each hand, therefore a directional control scheme was developed. Moving the left finger up provides up or forward motion, moving the left finger down provides down or reverse motion, moving the right finger up provides right motion, and moving the right finger down provides left motion. Three sensor systems have been used with the Tamara System. The first splint set utilized a design from Microswitch (3)

Magnetic hall effect sensors attached the ring finger of light cloth gloves. Magnets were attached to the "tunnel" section of the splints. This arrangement worked but the gloves were difficult to put on, and the sensors sometimes rotated out of position. The second set had sensors mounted at the top and bottom of the "tunnels" and a magnet was placed inside the ring finger of a glove. The magnet created voltages which were summed as an output. While moving the cables from the gloves to the splints made setup easier, staff asked if it was possible to eliminate the gloves. At this time it was decided to investigate whether photosensors could be used to track finger movement.

## DESIGN

The light splint design requirements included:
1) Rejection of ambient light levels
2) If (1) could not be accomplished in full sunlight, then outputs should go to zero.
3) No perceived response lag due to the controls.

Taking these requirements into account, a sampled system to read finger position was developed. A digital clock running at 4000 pulses per second is fed to a decade counter creating 10 time frames, repeating 400 times a second.

During frame 1 the ambient light for each sensor is read and stored in individual sample and hold circuits. Upon command, a sample and hold circuit samples a voltage for an instant and stores it for future use.

During frame 2 the infrared led for the upper left sensor ( forward ), is turned on, and the upper left sensor output is read and stored in a sample and hold circuit.

During frame 3 the infrared led for the lower left sensor ( reverse ), is turned on, and the lower left sensor output is read and stored in a sample and hold circuit

During frame 6 the infrared led for the upper right sensor ( right ), is turned on, and the upper right sensor output is read and stored in a sample and hold circuit.

During frame 8 the infrared led for the lower right sensor ( left ), is turned on, and the lower right sensor output is read and stored in a sample and hold circuit.

The sample and hold voltages for each axis are combined to produce a voltage related to finger position independent of ambient light.

Mathematically, the output of each axis is:

(upper sensor (led on))
-(upper sensor (ambient))
-(lower sensor (led on))
+(lower sensor (ambient))

Distributing the functions between the time frames allows for the slow turn off settling of the photosensors, and evens out the current drawn by the infrared leds.

To reduce the effects of the sample and hold offsets each sensors ambient and active sample and holds are on the same integrated circuit.

**EVALUATION**

The voltage output of the light splint relative to finger position has not been tested. It does increase as a finger gets closer to a sensor. Therefore it is possible to linearize the system by techniques such as Vectorplane (4). Perfect linearity may not be desirable, and the Vectorplane characteristics could be tailored to an individuals preference.

**FUTURE PLANS**

It appears possible to develop software and utilize some unused hardware of the Tamara System[2] to eliminate the separate electronic circuit explained here.

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Mark Bresler MBME
Rehabilitation Engineer
WB 403
O'Donoghue Rehabilitation Institute
P.O. Box 26307
Oklahoma City, OK 73126

(405) 271-3672

17.2

# Pressure Sensitive Joystick and Controller for Front Wheel Steering Wheelchairs

Fred Powell and Rafael M. Inigo
UVA Rehabilitation Engineering Center
Charlottesville, VA 22903

## Abstract

On conventional wheelchairs steering is accomplished by having one of the rear drive wheels rotate faster than the other or by having the wheels rotate in opposite directions. Great improvements are made in wheelchair controllability by replacing this conventional steering system with front wheel steering similar to that found on any motorized vehicle.

To control front wheel steering it was necessary to create a new type of joystick and controller. A pressure sensitive joystick and steering motor controller using hydraulic connections has been developed. The controller steers the front wheels at a rate proportional to the pressure on the joystick. This pressure proportionality is non linear; it depends on the forward speed of the chair, so that at high speed the steering is only slow and at low speed the steering will operate fast. The system provides excellent controllability, greatly surpassing the conventional joystick by taking full advantage of the front wheel steering capabilities of the chair.

## Background

Conventional wheelchairs, having large drive wheels in the rear and small caster wheels in the front, steer by having one of the drive wheels rotate at a different speed than the other. This system has several problems, all resulting in poor controllability. The overall problem is the slow response time of the system. The motors simply can not force the wheels to turn at just the right speeds to execute a precise turn. If the driver wants to go straight, but the caster wheels are not pointing in the correct direction, it is impossible to start out moving straight. This can cause problems in tight areas such as elevators. Another problem is trying to travel straight across an incline. Even with microprocessor feedback, it is difficult to keep the chair from turning down the incline.

A wheelchair with front wheel steering is an entirely different experience. The front wheels are simply steered in the desired direction and the chair travels in that direction precisely and immediately. The response is similar to any front steering vehicle, as the sluggish and uncontrollable feel of a conventional wheelchair is gone. When traveling across an incline the wheelchair has no tendency to deviate from its straight line path. The driver has the ability to direct the front wheels in any direction, and the chair travels only in that desired direction.

## Objective

With front wheel steering the conventional joystick is inadequate. As the conventional joystick moves from side to side, each joystick position must correspond to a steering position of the front wheels. The problem is that the small range of motion of the joystick is mapped over the large range of positions of the front wheels, so that a small change in position of the joystick corresponds to a relatively large shift in steering position. It therefore becomes very difficult to execute a smooth turn or to make minor adjustments in the position of the wheels since it is nearly impossible to keep the wheels at that position.

Our answer to this problem is pressure sensitive steering. By restricting left and right movement of the joystick and placing a pressure transducer on either side, the steering is done based on the pressure applied to the joystick. If a large pressure is applied, the wheels will steer very rapidly and the direction of the chair will change quickly. If a very slight pressure is applied then the steering motor will change the steering position very slowly, making only a minor change in the direction of the chair. If no pressure is applied to the joystick then the wheels remain in their current position, whether in a straight line or in a turn. In this manner the steering position of the wheels can be very finely controlled by applying slight pressures, or the wheels can be steered rapidly from one position to another with stronger pressures.

Several improvements over this basic idea have been made to increase controllability and safety. As was stated above, the speed of the steering motor is proportional to the applied joystick pressure. To increase the ability in making minor adjustments to steering position, while still being able to change steering position rapidly, the speed of the steering motors changes only slightly up to about one-half maximum pressure, and the speed of the steering motor changes at a large rate from one-half to full pressure.

Wheelchair velocity measurement was incorporated to make the joystick sensitivity proportional to the speed of the chair. When the chair is at rest, you want to be able to steer the wheels as rapidly as possible, however when the chair is at full speed, a very slight change in wheel position causes a very large change in direction so there is no need to steer the wheels very fast. It the chair were traveling at full speed and the wheels were steered at their full speed, the chair would flip. The velocity control is incorporated such that when maximum pressure is applied to the joystick, the wheels will steer at their maximum safe speed corresponding to the speed of the chair.

Method

The diagram of Figure 1 shows the entire steering system. The method chosen uses a small reservoir containing silicon fluid on either side of the joystick. A rubber nipple on one side of the reservoir contacts the side of the joystick. When pressure is applied to the joystick, the fluid is compressed. Hydraulic lines connect the fluid reservoirs to Foxboro pressure transducers on the controller board. By using hydraulic links to the joystick, electromagnetic interference problems are eliminated. From the pressure transducers the signal is first amplified with an instrumentation amplifier. The signal then splits and is amplified by a low gain amplifier and a high gain dead-zone amplifier. This creates the different joystick pressure to steering speed ratios. The outputs and then summed and fed into a voltage controlled amplifier. To measure the velocity of the chair an optical disk encoder was mounted to the end of one of the drive motors. The encoder

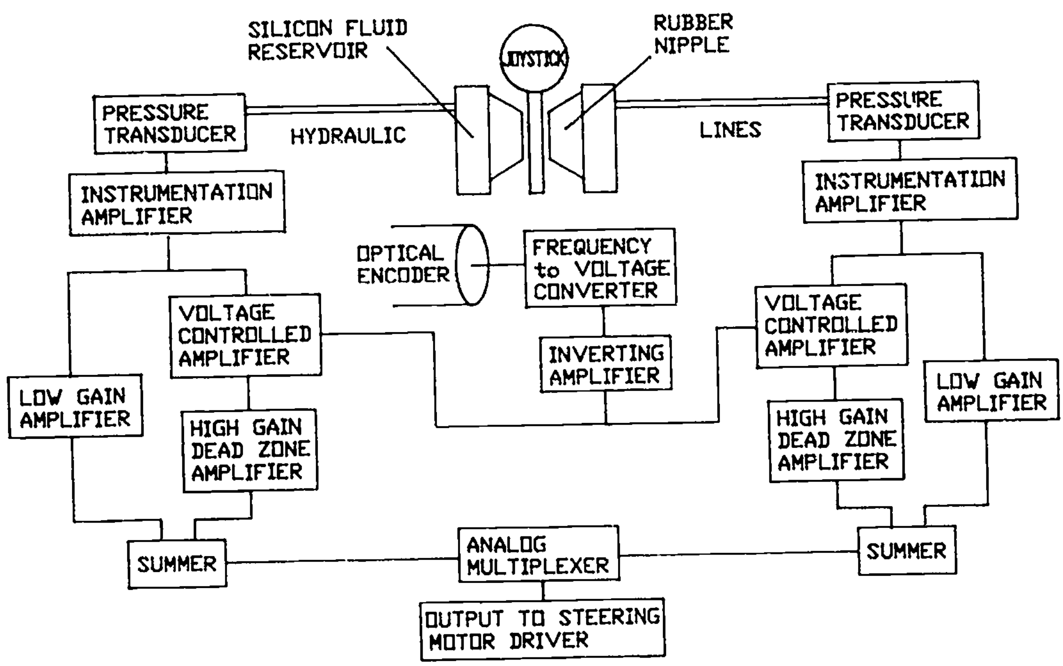


Figure 1. Pressure Sensitive Joystick Controller

output is fed into a frequency to voltage converter[1] which creates a voltage proportional to the speed of the chair. The voltage signal is inverted and used to control the voltage controlled amplifier[1]. Therefore when the chair is stopped the voltage controlled amplifier is at full gain and the steering motor can run fast; and when the chair is at full speed the gain is small and the maximum speed of the steering motor is low. The output of the voltage controlled amplifier is fed into a regular amplifier, increasing the effect of the variable gain. The signals from the left and right channels are then combined for controlling the steering motor driver, whose inputs are 6 +-3 volts. 6 volts is the zero, 6 to 9 volts rotates the steering motor in one direction, and 6 to 3 volts rotates it in the other.

## Results

The new joystick was installed in the front wheel steering wheelchair and tested under different conditions. It was driven across inclines, through narrow hallways, in elevators, over grass hills, etc.

## Discussion

The new pressure sensitive joystick and controller proved to be far superior to a conventional joystick in their ability to take advantage of the front wheel steering capabilities of the wheelchair.

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## Acknowledgements

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UVA Rehabilitation Engineering Center
Box 3368 University Station
Charlottesville, VA 22903

# A FAULT-TOLERANT OPTICAL JOYSTICK CONTROL INTEGRATED CIRCUIT FOR A POWERED WHEELCHAIR

Cyrus Malek-Mohamadi, James H. Aylor, Andrew J. Schwab

Center for Semicustom Integrated Systems, University of Virginia, Charlottesville, Virginia 22903

## ABSTRACT

This paper describes the design of a new highly-reliable powered wheelchair joystick control integrated circuit (IC) which will interact with a highly-available microprocessor based wheelchair system also currently under development. The IC has been designed using silicon compilation technology using a 2 micron, double metal, double poly CMOS process. This joystick system utilizes hardware redundancy, on-chip self-test, and replicated data paths to detect single stuck-at faults (per IC) and insure safe operation of the wheelchair at all times. Each circuit can fit inside a single integrated circuit chip so that the parts count is minimized. Data is transferred to the microprocessor in parallel or via an ISO compliant serial interface.

## BACKGROUND

Traditionally, electric wheelchair joysticks contain variable resistors, which with proper circuitry, produce a varying voltage on the input of an analog-to-digital converter (ADC). The digital output of the ADC is sent to the microprocessor controlling the wheelchair. The problem with this configuration lies in the potentiometers which can become dirty, causing malfunctions or eventually wear out due to friction. This problem can be overcome by using optical encoders that are not prone to frictional degradation - no moving parts in the encoder contact other parts.

Several types of optical encoders are available. Relative optical encoders output two waveforms in quadrature and one optional waveform that indicates the encoder's home position. The purpose of the quadrature signals is to determine which direction the encoder is turning. The choice of relative optical encoders (absolute optical encoders are considerably more expensive) requires additional signal conditioning before the encoded information is passed to a microprocessor (no ADC is needed here). This additional conditioning is the focus of the rest of this paper.

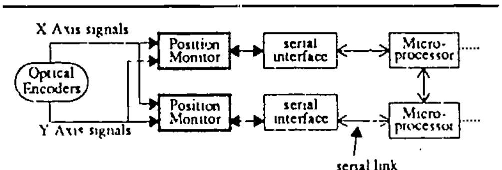


Figure 1

## DESIGN

The design and simulation of the position monitor IC was carried out using the ChipCrafter™ silicon compiler tool from Cascade Design[1], Mentor Graphics ICStation[2] and Mentor Graphics QuickFault. The position monitor IC is designed to examine the three outputs of each of the two optical encoders (one encoder per axis) and determine a position count (see Figure 1). Redundant position monitor ICs are used to eliminate common mode failures, by providing identical, independent data paths between the joystick and the microprocessor. Early in the design process a decision was made that this system conform to an ISO interface standard being developed for electric wheelchair communication[3]. This standard is not yet final, but certain aspects that were agreed upon at the time were taken into account in this design.

As shown in Figure 2, the functional design was broken down into three primary blocks: data path, test, and microprocessor interface. The microprocessor interface has been partitioned as a separate project to keep the IC costs down and reduce the overall design complexity. The data path and test blocks are combined onto a single integrated circuit (IC) requiring approximately 2500 microns on a side with a two micron CMOS nwell process.

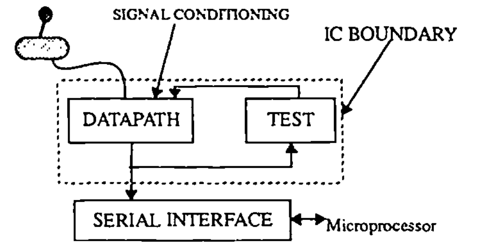


Figure 2

A primary design criteria of the overall wheelchair project was that it would tolerate one fault in the joystick circuitry and still continue operating normally. Dual sets of x and y data are processed to achieve this goal. One whole IC may fail and the microprocessor will still receive correct joystick position information. This scheme infers that the microprocessor must somehow determine if one of the ICs is bad (explained under 'Test unit'). Each IC has on-board test capabilities that are used to determine the status of the IC, while the microprocessor keeps a history of position information that is used to determine if the data from the two position monitors begin to differ significantly.

### Data path unit

The asynchronous output signals from the two optical encoders (three signals per encoder) are processed by the data path. The IC's inputs contain Schmitt-triggers (built into the IC's pads), which reduce metastability effects on the signals. Metastability is a condition where signal levels remain in an intermediate state between logic-1 and logic-0 levels. Schmitt triggers eliminate or reduce the size of this intermediate state.

The data path unit contains two identical paths for the x- and y-axes respectively as shown in Figure 3.

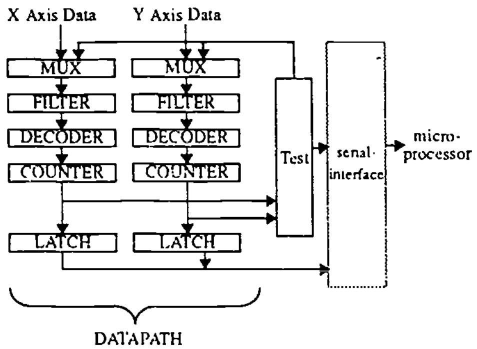


Figure 3

Multiplexers: The first block in the data path is a set of multiplexors. The multiplexors are used to switch between on-board test vectors generated in the test unit (test mode) and actual signals from the optical encoders (run mode).

Filters: Next, the signals are filtered with digital filters to shape the signals (see Figure 4) into better digital waveforms by eliminating spikes, runt pulses, and metastability problems. Each filter is a series of D-type flip-flops which passes the input signal on if it remains at a logic level for a minimum of three clock cycles, otherwise the filter output remains the same. Finally, the filters synchronize the output signals to the system clock.

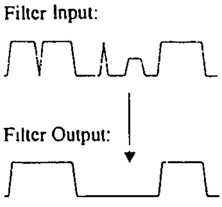


Figure 4

Decoder: The filtered signals are decoded to control seven-bit up/down binary counters. Three signals are generated in this block: count direction, count enable, and home initialization.

Counter: The counter is a seven-bit up/down counter with parallel load capability, that has 64 bits of resolution in either direction. Additional circuitry has been added to allow the counter to be set to 40HEX (counter's middle value) when the home initialization signal is received. Normally, home initialization occurs each time the joystick is in its resting (center) position. The parallel load feature is used by the microprocessor to reload the counters with data after a test has taken place, or the microprocessor can use this as a test feature itself (i.e. to insure proper operation of the serial interface).

Latch: A seven-bit latch is used to buffer the position data between the position monitor IC and the serial interface.

## Test unit

Test vectors and overall control signals for the position monitor are generated in the test unit. This unit communicates with the serial interface for its instructions and status (error) reports. Most of the layout in this unit was generated with a finite state machine language tool called FINESSE[4], included with the ChipCrafter software. In addition to this test unit, a comparator and combinational logic are used to check for faults in the data path. While the comparator examines both x and y-axis data paths, the combinational logic determines if the y-axis counter is in its home position. The test circuitry can also be functionally tested off-line through built in scan-path test structures.

When instructed by the serial interface unit, the test unit will enter its test mode to determine the working status of the chip. First, the comparator is checked for any logical stuck-at faults. Test vector coverage is 100% for logical single stuck-at faults. Next, both data paths outputs are compared while counting up 128 counts and back down 128 counts. Upon completion of this test, a final test is made to determine whether the home-initialization pulse properly sets the counters to 40HEX. Any testing of parallel load feature is left up to the microprocessor.

Errors detected by the self-test procedures are reported to the serial interface via two error lines: compare error and home error. While the microprocessor will routinely initiate a test sequence on the position monitor ICs, it will also initiate tests when the data from both ICs significantly differs. Based on the test results, the microprocessor will determine whether or not future data from an IC is valid.

## Serial Interface

In order to conform to the ISO standard currently under development for powered wheelchairs, an optional serial link has been designed to provide additional flexibility between the joystick position monitor and the microprocessor. The standard calls for communication between the microprocessor and peripherals are to be managed in a serial fashion. Data words are eight bits long with two bits for start and stop. Using this specification, the most significant data bit (MSB) was chosen to distinguish data words from control and error words. The most significant bit is a logic zero for position data and a logic one for control and error data. In this way all eight bits of the serially transmitted word are used. A more detailed description of the interfacing standard can be found in [3].

To reduce fabrication costs in the first phase of this project, the serial interface is dedicated to a separate IC. The serial interface circuit is currently under development using an Actel field programmable gate array (FPGA). The serial interface consists of circuitry to manage the communication between the position monitor described in this paper and the microprocessor. It is simply an intelligent universal asychronous receiver and transmitter (UART); it sends position and error data to the microprocessor, and accepts and decodes commands and data from the microprocessor to control the data path operation. Also, it controls parallel load, reset, and test operations in the position moniter.

## OPERATION

There are three modes of operation for the position monitor: run, test and parallel load.

In run mode signal input to the data path originates from the optical encoders. The counter continuously tracks the joystick's position, with a clock speed of 2 megahertz, derived from the microprocessor's clock. When the microprocessor is ready to receive a pair of positions (x and y), a control word is sent to the serial interface, which in turn latches the output of the counters and begins to transfer the position data back to the microprocessor. The x-position data is first sent, followed by the y-data. The microprocessor stores a limited history of the position data it receives and it checks current measurements against this data to determine if a self-test or joystick reset is necessary.

Self-testing begins when the microprocessor transmits a test control word. While in this mode, a control line from the test unit to the serial interface unit is lowered, indicating test mode is entered. All tests are completed before the test mode can be exited; applying a RESET is the only way to circumvent this feature. The basic operation of this mode is described above under 'Test unit'.

The microprocessor may choose to restore the value of a counter by transmitting a parallel load control word, followed by the data to be loaded. In this case, the serial interface strobes the parallel load line to the test unit and presents the data to the counter's data inputs, which is latched on the next clock edge. The x and y-counters may be loaded independently or jointly. Again this mode can also be used as a test by the microprocessor for the parallel load feature.

The microprocessor may also request a hard reset of the position monitor. In the case of any reset, the monitor will start up in run mode with the counters set to 40HEX (also the home position).

## CONCLUSION

The design of the position monitor IC was strongly guided by fault tolerance, self-testability, simplicity, conformation to standards and existing systems, and of course low cost. All of these features were incorporated to some extent.

Considerable possibilities remain for future enhancements to this project: the joystick resolution may be increased (larger counters); different fault tolerant schemes may be employed; the input interface (to encoder or other device) can be generalized to work with other peripherals such as sip/puff switches. As it stands, this project requires two chips: one chip for the position monitor and one for the serial interface. These two devices could be combined into a single IC incorporating additional test features.

At this point in the project, extensive simulation has taken place and the position monitor design is ready to be shipped for fabrication. Software to run on the wheelchair microprocessor is yet to be coded.

## ACKNOWLEDGMENTS

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Address correspondence to:
Cyrus Malek-Mohamadi
Department of Electrical Engineering
Thornton Hall
Room E210
University of Virginia
Charlottesville, Virginia 22903

17.4

# An Electric Wheelchair with Special Features

Thomas T. C. Choy, John T. K. Koo
Biomedical Engineering Laboratory, Department of Electronic Engineering
Chinese University of Hong Kong
Shatin, N. T., Hong Kong

## Abstract

A new design of electric wheelchair is presented which incorporates reduction in size and weight, adjustability of seat height of backrest, width and up-folding of armrests and seat rotatability. Smooth acceleration and tracking controllability is also achieved via use of close-loop μC-based control circuitry. The design is aimed at providing a more suitable model of power wheelchair for the use of the smaller-sized Orientals in confined indoor space in general.

## Background

Inspite of its availability for quite some time, the present day electric wheelchair, in general, has a lot of ground for improvement. Its bulkiness and weightiness and its lack of adequate seat adjustability and hence comfortability are often points of complaint from users particularly in the Oriental countries. This is understandable as all electric wheelchair manufactured in the West are basically designed with the nominal local human size and physique and local environment in mind. Orientals are in general smaller in built and less powerful in physique. The crowded living condition is also a sharp contrast. The difficulty in achieving smooth acceleration (particularly form start) and deceleration is another cause of concern. The difficulty in tracking an intended path with differential loading on the two sides due to different ground condition, especially when one wheel is caught, is yet something else to improve. There is a genuine demand for powered wheelchairs of suitable design (similarly for manual wheelchairs) in the Orient as electric wheelchairs serve a different category of users. Presently all powered wheelchairs are imported ones and as a result can serve only a minority of the potential users.

## Problem Statement

Problems to tackle include (a) reduction of size and weight, (b) seat adjustability and (c) acceleration and straight-line control.

## Design Methodology and Implementation

(a) Size and Weight Reduction: The problem has been solved by making reference to the average size of the Orientals and realizing the vehicle is mainly for indoor or not-too-hostile outdoor environments. Having consulted relevant occupational therapists and would be users of different types of handicap and the aged, it is possible to trim down the overall size to 32" (length) by 22" (width) [Fig. 1 a, b, c]. Moreover, to enable the vehicle to pass even a narrower strip, without sacrificing side-toppling stability, the 5-inch front castors can fold in from a normal span of 22 inches to 17 inches (the width of the rear drive wheels) via use of a motor-driven lead-screw and Y-link [Fig. 2]. Using two 24 AH batteries, 12-inch BMX wheels and aluminium alloy frame, the overall weight is reduced to some 72 pounds.

(b) Seat Adjustability: As the potential user will be using the vehicle most of the time during the day, a seat that can be adjusted to give the user maximum comfort is useful and important. Our approach is to adopt an rotating office chair to the frame work and make modifications to the seat support, the back support and the armrests. Since these are all one-time adjustments, a simple track and stud-lock design is adopted for all except seat rotation and armrest up-folding. A locking screw with large handle for easy handling is used for the former and, for the latter, an end-of-travel catch for the horizontal and vertical dead-end positions. The armrest, in the vertical position, can be pushed in to a span of 17 inches if required so as to enable the vehicle to pass a narrow corridor or doorway of about that width [Fig. 1 a, b, c]. With the seat detached, the whole thing is reduced to two pieces each no higher than 17 inches and hence can be easily put away in the boot or even the backseat of a car.

(c) Acceleration and Straight-line Control: Difficulty in achieving smooth acceleration, particularly in starting, in an indoor area of rather confined space is often a cause of deterrence to some potential users of electric wheelchair. Asymmetrical degree of ground-contact roughness, free-wheeling due to slip and abrupt change of travel direction can, on the other hand, cause difficulty in tracking. With the user closing the control loop, the former problem often results in oscillation in acceleration (ie. a jerky motion) and the latter in oscillation about the desired track (ie. a wabbling motion) and can easily lead to collision.

Our solution is to provide an "adaptive" close-loop control independently for each drive wheel from which the instantaneous current and velocity (both speed and direction) are sensed and fed back for comparison with the chosen designed reference for control purposes.

Motive power is provided by two 0.145KW/0.055 Kgm DC motor each with a rated current of 6.25A at 24V. Reversible drive is achieved via a H-bridge arrangement of power MOSFETS (MTH40N10) which are driven in turn by the LM324 and DS0026 drivers on the high and low side respectively.

Heart of the controller is the microcontroller μC8031. An 8-bit control signal provides a 256-level of PWM for fine speed control for each motor [Fig. 3].

The feedback signals are sampled at 10ms intervals and compared with the predetermined target speed characteristic corresponding to the controller (eg. joystick) setting and chosen range of mild, moderate or hard acceleration. Speed difference exceeding the set band will cause the drive signal to be set to the extreme value within the set limit (Band Band control type) causing the motor to approach the target speed in the shortest possible time. In order to minimize the effect of unequal loading, gravitational or frictional, that may lead to a side-tracking motion, the control strategy is changed to having the faster-moving wheel follow the slower-moving one once the instantaneous differential speed exceeds a preset limit.

## Performance Evaluation and Discussion

A length of 32" is not much shorter than the average length (about 34"), but the minimum width of 17" is a significant advantage in confined space maneouvering. The overall weight is 72 lb with two 24 AH batteries and is increased to 95 lb if the batteries are replaced by two 38 AH ones for longer distance travel between recharging. Up to 4 hours continuous operation is possible with the former and hence overnight recharging only is required for average indoor use. The larger batteries are recommended for outdoor use in view of the rougher ground condition and possibly longer hop required between recharging. With the existing motor-gearbox combination (3000 rpm, 50:1) the maximum speed achievable with an average body weight of 150 lb is 3.1 fps, an acceptable indoor speed figure.

The available ranges of seat adjustments are: 5" for height, 2" for depth, 3" for backrest height and 2.5" x 2 for armrest width. These ranges are sufficient to cover more than 95% of the population.

To evaluate the speed and tracking control capability, the speeds are actually derived from the correspondingly sampled voltage since actual speed measurements in motion are difficult to made. Fig. 4 a, b show the acceleration and deceleration characteristics for (i) uneven loading and (ii) (iii) even loading on the two wheels. Part (i) in Fig. 4(a) depicts the speed curve of the right wheel with and without (relevant circuit disabled) interspeed comparison. With the interspeed comparison circuit intact, the reference speed for right wheel comparison is changed from the normal target speed to the instantaneous left wheel speed once the preset differential speed limit is exceeded. As can be seen, smooth acceleration can be achieved and off-tracking is much suppressed.

## Conclusion

The several desired features have all been achieved with this development model. Rooms for improvement at this stage may perhaps be (a) a more powerful motor (eg. 1/4 HP) with a smaller gearbox ratio (eg. 40:1) to improve the maximum speed and (b) temperature sensing and control for motor protection in locked wheel overload condition.

## Acknowledgements

Funding for research was provided by University and Polytechnic Grant, United College (CUHK) Student Campus Work Scheme Fund and Departmental Research Grant.

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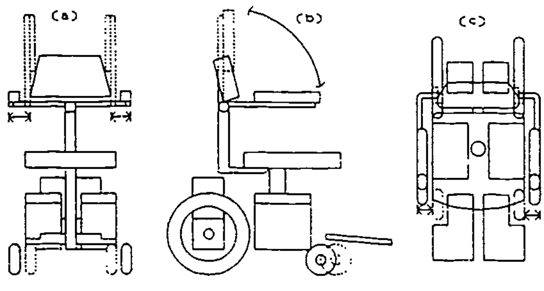



Fig 1 Schematic Picture of Wheelchair
(a) Front View
(b) Side View
(c) Top View

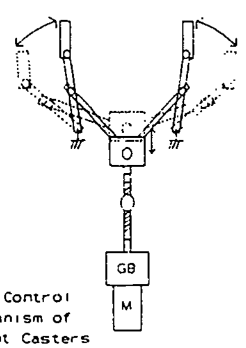



Fig 2 Control Mechanism of Front Casters

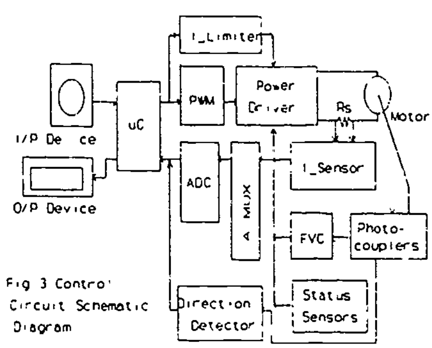
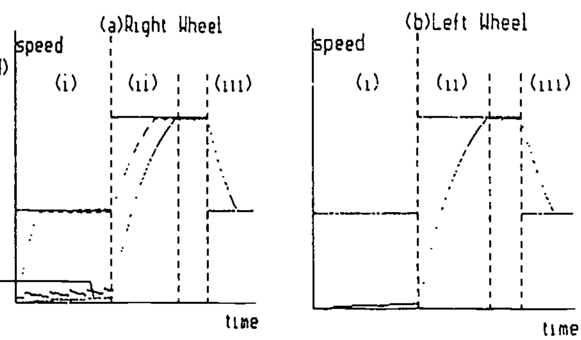



Fig 3 Control Circuit Schematic Diagram

Fig.4 Speed Performance Curve

(i) Asym. Load(L/s Load>R/s Load)
(ii) Sym. Load; accelerating
(iii) Sym. Load; decelerating

——— Target Speed
——— Actural Speed with interspeed comp.
– – – – Actual Speed without interspeed comp.
Modified Actual Reference Speed



# Microprocessor Based D.C. Brushless Motor Controller for Wheelchair Propulsion

Fred Powell and Rafael M Inigo
UVA Rehabilitation Engineering Center
Charlottesville, VA 22903


## Abstract

The mechanical brushes which are standard in permanent magnet D.C. motors have several drawbacks. D.C. Brushless motors use electronics in place of the brushes, producing a motor which has several benefits including higher efficiency and maintenance free operation.

A microprocessor based digital closed loop brushless motor control system has been developed for electric wheelchair propulsion. The wheelchair control algorithm operates on an 8088 based single board computer, and each motor is controlled by an HCTL-1100 micro-controller.


## Background

A D.C. brushless motor is designed to have similar characteristics to a regular permanent magnet D.C. motor, linear speed/torque and linear speed/voltage curves. The construction of the motor is actually very similar to a 3 phase A.C. motor [1]. The brushless motors which we are using have a 4 pole permanent magnet rotor and a 3 phase stator. The control system of the motor tracks the position of the rotor, energizing each phase at the correct time and in the desired order. The direction of the motor is reversed by reversing the order of two of the phases. The simplest brushless motor controller consists of 3 Hall effect sensors and transistors. Hall effect sensors in the motor produce a voltage in response to the magnetic field of the rotor. This signal is used to turn on a transistor which supplies power to one of the motor phases, i.e. each Hall effect sensor is located such that it energizes a phase at the correct time.

## Objective

The benefits of D.C. brushless motors over regular D.C. motors make them ideal for electric wheelchair propulsion. With regular motors, the friction of the brushes on the armature causes the brushes to wear out. In addition to mechanical losses, the brushes also produce electric losses and produce electric noise which can interfere with computer and collision avoidance equipment operation. Brushless motors eliminate these problems. With their measured efficiency approaching 80% over the normal region of operation, these motors will provide extended range for the chair. They also produce a much higher continuous torque. Since the only source of friction is the bearings at either end of the rotor, brushless motors provide maintenance free operation, thus reducing the possibility of an unexpected failure. They also provide nearly silent operation. When a computer is used to control the motors, as is the case in the developed system, phase advance and phase overlapped can be used to provide increased torque and speed.

## Method

The brushless motor controller has been implemented using the Hewlett Packard HCTL-1100 high performance, general purpose, digital motion control IC [2]. The host processor is an 8088 based LPM-SBC40 single board computer on the STD Bus. The motor drive consists of IR2110 MOS gate drivers with an all N-channel power MOSFET 3 phase bridge. System software is written in C on a host PC, then downloaded into the single board computer using a remote debugger. In the final system, the executable code will be burned into an EPROM on the single board computer.

Using of the HCTL-1100 provides many benefits in controlling the brushless motors. The HCTL-1100 is essentially a computer dedicated to motion control; there is one HCTL-1100 for each motor. By programming the desired options for the system and giving a desired command, the motion controller will execute the command closed loop without any interaction with the host processor, freeing it to perform other operations. An optical encoder installed on the motor shaft provides position feedback directly to the motion controller. Several different control modes are provided, including position, proportional velocity, and integral velocity. The HCTL-1100 controls velocity and acceleration, can lock the rotor, and performs dynamic braking. For increased speed and torque, the HCTL-1100 can be programmed for phase advance and phase overlap. With phase advance, the time at which the windings are energized is dependent upon the velocity of the rotor; at higher speeds the windings are energized a little sooner. Phase overlap means that all three phases are energized at the same time. Normally, there are only two phases energized at once, one positive and one negative. The current commutation logic does not allow for phase overlap, however a new controller has been designed and is being built which takes advantage of this feature, providing an estimated 10 to 15 percent increase in torque.

The LPM-SBC40 single board computer is actually part of a previously designed optimal adaptive wheelchair control system [3]. Modifications to the system will be made to interface it with the HCTL-1100 micro-controllers and take advantage of the features of brushless motor.

## Results

Figure 1 shows the construction of the current system. The brushless motor and controller have been tested using a dynamometer which measures input power and current, and output speed, torque, and power. The following graphs display some system characteristics. Currently the software is being written to interface the brushless motor controllers with the adaptive wheelchair controller, and necessary parts are being collected to install the entire system in a chair.

**Discussion**

Figure 2 shows the excellent efficiency and high torque of the motor and controller. Figure 3 shows the linear speed-torque characteristic like that of commutator D.C. motors. Note, however, that the line is not straight. High speed slopes are higher due to phase advance. Figure 4 shows the linear current-torque characteristics also similar to commutator D.C. motors. The effect of pulse width modulation on the current-torque relationship can be seen on graphs 4 and 5. For pure D.C., motor current is dependent only on motor torque, i.e. current is independent of speed and applied voltage. Figure 5 shows that a higher PWM produces a higher maximum torque, and Figure 4 shows that given a maximum continuous current, a lower PWM produces a higher torque. The software will incorporate this information, allowing the motor to produce high torques outside of the continuous duty zone for a short period of time, and adjust the control parameters to insure that continuous operation is inside the continuous duty zone. Figures 6 and 7 show the effect of phase advance on motor speed and current. We see that phase advance substantially increases motor speed, but the increase is matched by an increase in current. Again, the software will invoke these features when demanded by the user, producing the needed speed and torque while maximizing efficiency and minimizing current. We conclude that sophisticated control with brushless motors can be achieved by virtue of the HCTL-1100 motion control IC linked with a microprocessor.

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UVA Rehabilitation Engineering Center
Box 3368 University Station
Charlottesville, VA 22903

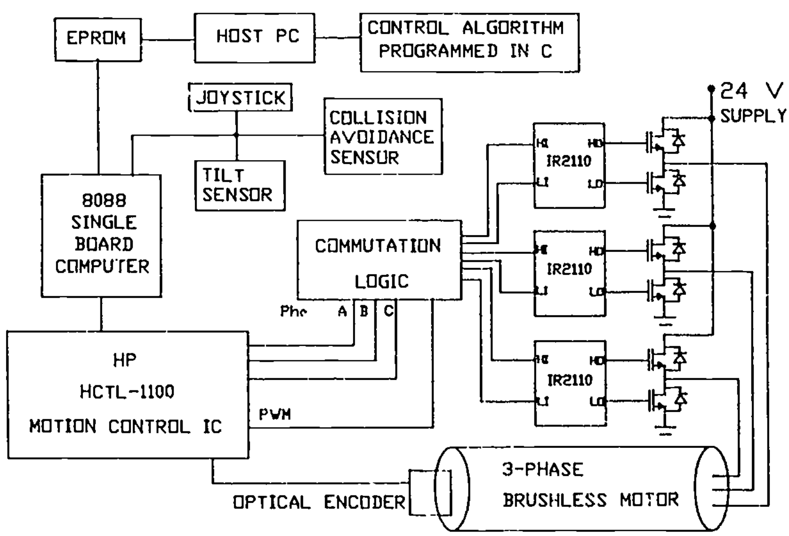


Figure 1. D.C. Brushless Motor Control System

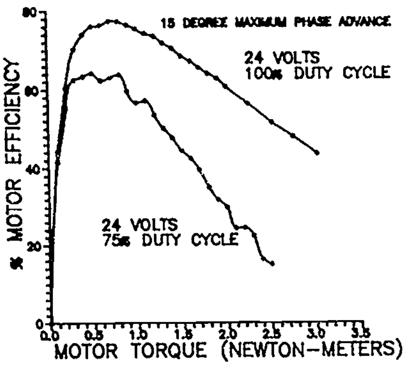


Figure 2

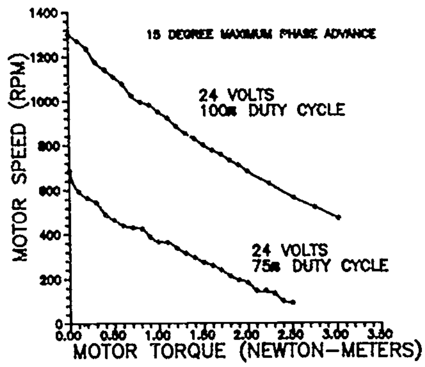


Figure 3

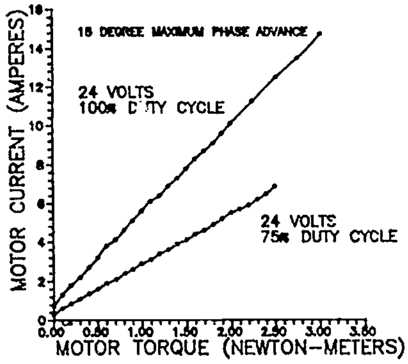


Figure 4

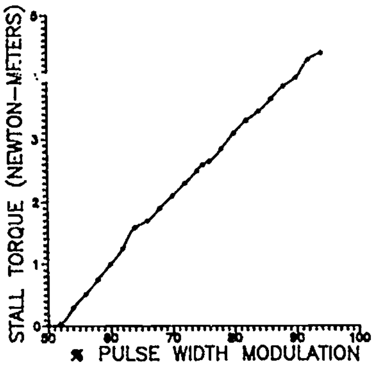


Figure 5

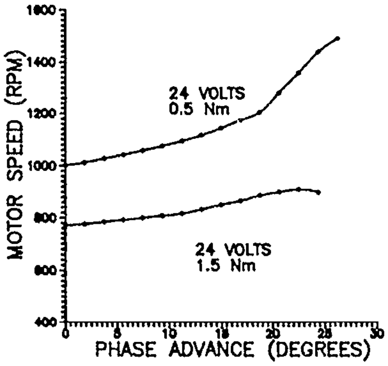


Figure 6

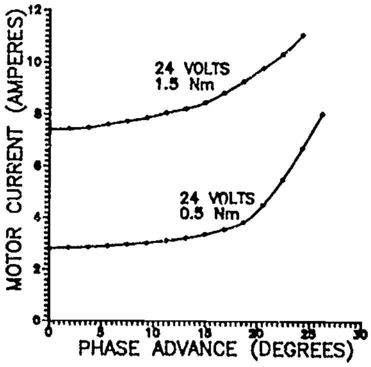


Figure 7

17.6

# POWERED WHEELCHAIR GEARBOX LUBRICATION

M.R. Ford, J.J. Kauzlarich & J.G. Thacker
University of Virginia Rehabilitation Engineering Center
Charlottesville, Virginia USA

## Abstract

The mechanical losses in gearboxes of an electric wheelchair drive system are a major contributing factor to the inefficiencies encountered in chair operation. The lower the efficiency occurring in the gearbox results in an overall reduced electrical/mechanical conversion affecting the operation time for each recharging of the battery. This paper presents a few different options to increase the time interval between battery recharges.

## Background

The drive system of an electric wheelchair consists of a permanent magnet DC motor which is controlled by a Pulse Width Modulator (PWM), a reduction gear box and a pulley-belt arrangement. The PWM is supplied by a constant twenty four volts; two twelve volt batteries. As the operator maneuvers the control stick the PWM sends varying length pulses of energy to the motors which determines their speed and direction. The motors are each attached to a separate gear box. The gears inside the box will reduce the rotational speed of the motor and at the same time increase its torque capability. The output shaft of each gear box is then connected to a pulley which drives the rear wheels of the chair by a V-belt system. The belt is used for its ability to absorb shock and to function as a clutch.

## Discussion

A common practice is to use a gear box utilizing a worm and a single enveloping gear. This allows the shaft of the motor and the gear box output shaft to be at right angles to one another which places the motors in a parallel position to the side framework. A worm gear can also be designed to be self locking, an added safety feature. Although as a space saver it is not a highly efficient gearing arrangement. The worm is driven by the motor and works much the same as a power screw thread. As the worm turns it drives the gear which is partially wrapped around the worm. Because of the sliding contact between the worm and the worm gear high friction forces occur lowering the efficiency. A spur gear on the other hand consists of a small pinion and a larger gear. The pinion is driven by the motor and transmits power to the gear. Due to involute cutting of the gear teeth their is rolling friction and much less sliding friction as apposed to the constant sliding friction in the worm gear. The efficiency is therefore higher in the spur gear arrangement than that of a worm gear system[1]. If the spur gear were to be used it would not allow the chair to be folded for storage due to the shafts of the pinion and the driven gear being in a parallel line with one another. This is an important drawback for spur gearing in wheelchair design.

Assuming the necessity for compactness of wheelchair storage, another alternative is possible. The efficiency ($\eta$) in a worm gear is represented by the equation:

$$\eta = \frac{\cos\phi - \mu \tan\lambda}{\cos\phi + \mu \cot\lambda}$$

where $\lambda$ is the lead angle of the worm thread, $\phi$ is the pressure angle normal to the gear teeth, and $\mu$ is the coefficient of friction[2]. So for a particular worm gear the only variable which can be controlled is the coefficient of friction. The most common form of lubrication in a production gearbox is a very viscous black grease. It has good properties at high speeds such as supporting high loads, a fairly low coefficient of friction and rapid heat dissipation. However at the relatively low speeds that a wheelchair will be operated the thick grease causes a lot of drag and has a higher coefficient of friction decreasing efficiency. Therefore an alternative form of lubrication is desirable.

Two substances that primarily work on the same principal, possess the properties of very low coefficients of friction and the ability to be used at low speeds. The first, a lubricant known as polytetrafluoroethycne (PTFE) is made of a polymer composition. It consists of a chain of ethylene gas in which all the hydrogen atoms have been replaced by fluorine.

```
  F   F   F   F   F   F
- C - C - C - C - C - C -
  F   F   F   F   F   F
```

Due to the strong covalent bonds of the carbon atoms connecting the polymer chain and the weak van der Waal forces between the various chains, "sliding" is encountered with minimal shear forces. This characteristic results in a very low coefficient of friction and is ideal for the sliding motion between the threads of the worm and the teeth of the enveloping gear. As the surfaces slide past each other the PTFE chains perform as microscopic slides. Small amounts of PTFE contained in an oil resin are applied only to the teeth surfaces eliminating the drag that is experienced by the total immersion of the gears in the grease and increasing the efficiency. The second lubricant is a dry film molybdenum disulfide. As mentioned this works in a similar manner to the PTFE. Each layer of molybdenum atoms is sandwiched between two layers of sulphur atoms, and the bonds are strong covalent chemical bonds. The adjacent sulphur atoms possess weak van der Waal bonds allowing the layers to pass over one another easily, again with only minimal shearing forces[3]. Although easily split along the sulphur molybdenum disulfide interface it is very strong in the perpendicular direction contributing to a long wear life. The dry film $MoS_2$ is applied to the worm and gear by dipping them into a liquid slurry and allowing it to dry. The parts are then baked in an oven until hard.

## Method

The power was measured to determine the different efficiency ratings for these different gearing possibilities. A dynamometer was used to determine the input power delivered to the system and to measure the power that was put out by the system. The efficiency was then calculated by power output divided by power input. Four different motors, all of the same type were tested to find an average efficiency rating. The one that best fit the average was then used as a constant for the two different gearbox configurations and the lubrication variations. The gear boxes were connected to the motor one at a time. The system was then tested at a constant load while the voltage was varied. Changing the amount of voltage is equivalent to the varying length pulses sent out by the Pulse Width Modulator simulating the amount the joy stick is deflected to increase or decrease velocity. One characteristic of a DC motor is that the speed of rotation is in direct proportion to the voltage input. For each input voltage and maintaining a constant load (input amperage) the power in and power out can be recorded and at the same time the rotational speed can be used to calculate the wheelchair speed. The linear velocity of the chair can be determined from the rotational speed of the gear box output shaft and the measured radii of the two pulleys and the radius of the wheelchair wheel by the following equation:

$$VEL_{WC} = 2\pi \left[ \frac{(\theta\ v)_{GEAR}\ \rho}{\gamma} \right] X\ \frac{60}{1000}$$

where θ is the RPM of the output shaft, υ the radius of the pulley connected to the gearbox output shaft, ρ the radius of the rear wheel and γ the radius of the pulley on the rear wheel. The efficiencies found at each voltage level for the motor and gearbox in series were then divided by the efficiency of the motor by itself resulting in the gearbox efficiency. The same procedure was followed using a spur gear of approximately the same size and weight. This was done for both the manufacturers grease and the PTFE lubricant. The results of the data for both the worm gear and spur gear are shown in Figure 1. The next test involved using the baked on $MoS_2$ dry film lubricant. This was done for the worm gear box only due to the plastic gearing of the spur gear used in the testing. The worm gear was again connected to the motor and a constant load applied but instead of varying the voltage a constant 24 volts was maintained to determine the wear potential of the completely dry lubricant. The result is shown in Figure 2.

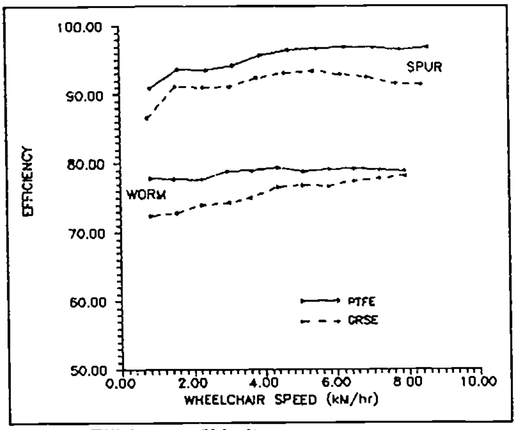


**Figure 1: Efficiency vs Velocity**
Worm Gear and Spur Gear

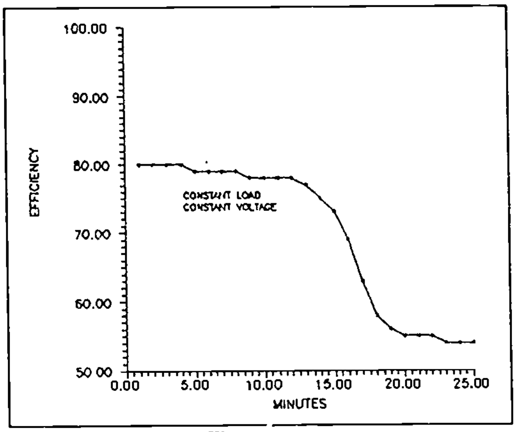


**Figure 2: Efficiency vs Time**
Dry Film Lubricant

### Experimental Results

As Figure 1 illustrates, the spur gear does have an average of a seventeen percent higher efficiency rating than the worm gear. Installation of spur gears of the same size and weight as the worm gears would increase the time and distance possible by each recharge. However, as mentioned before, using the spur gears would restrict the wheelchair's storage capabilities, due to the spur gear's characteristic of input and output shafts being parallel. Also shown in Figure 1 is the increase in efficiency of the PTFE over the grease in both the spur gear and worm gear. Using the PTFE in the worm gear would increase the efficiency especially at the lower speeds. The speeds, consequently, that are most frequently encountered at which turning and basic maneuvering occur.

The curve in Figure 2 indicates that the dry $MoS_2$ by itself, although initially with a high efficiency rating experiences a steep decline resulting from the removal of the lubricant due to wear and high temperature build up. The next attempt was to try and apply both the grease and the PTFE, alternatively, on the gears that have had the dry film baked on. The results as shown in Figure 3 would illustrate that in both cases the efficiency was increased when the oil based lubricants were applied in addition to the baked on lubricant.

### Conclusion

The experimental results would indicate that although the baked on $MoS_2$ is not a good lubricant by itself, when used in addition to an oil based lubricant it improves the overall efficiency. Also due to its strength in the direction normal to its planar surfaces it may increase the wear life of the gears.

In either case the PTFE consistently shows an improved efficiency rating over that of the manufacturers typical thick grease.

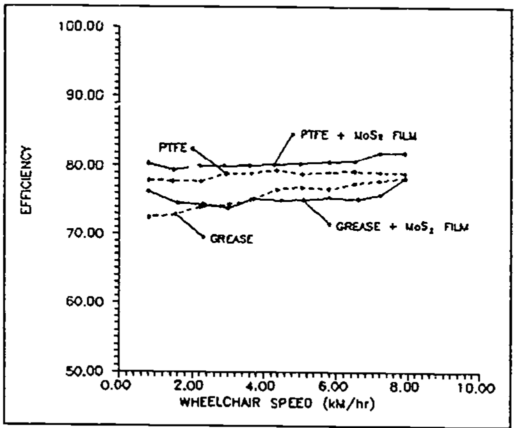


**Figure 3: Efficiency vs Velocity**
Grease and PTFE (Solid Film)

**Acknowledgement**
Funding for this research was provided by the University of Virginia Rehabilitation Engineering Center under the DOE,NIDRR Grant Number H133E80003

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M.R. Ford
UVa REC
P.O. Box 3368, Univ. St.
Charlottesville, VA 22903

# A Pneumatic Powered Extendable Mouthstick Prototype

S. Scott Stroud and W.S. Harwin
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

## ABSTRACT

People who are unable to use their hands can benefit from using a mouthstick (orthodontic prosthesis) to perform tasks usually done by the hands. People with the additional limitation of little or no anterior/posterior head motion may benefit from an extendable mouthstick. Such a device would allow an individual to access objects in a larger region, thus allowing an individual to participate in more normal daily activities such as operating a computer or switch. The extendable mouthstick prototype described incorporates a pneumatically bite-controlled valve, operating a piston and cylinder arrangement. The force of the user's bite controls the extension of the mouthstick.

## BACKGROUND

Mouthstick prostheses are comprised of intraoral and extraoral parts. The intraoral part serves as the interface between person and prostheses. Its design is very important in helping maintain the oral health of the user. The extraoral portion consists of the accessory tips and the body which attaches the tips to the intraoral part. Depending upon the type of mouthstick, the design of the two parts may be dependent upon one another. Physiological design considerations and material considerations for the intraoral portion can be found in the literature [e.g., 1-7]. Thus far, our research has been confined to the extraoral portion, while continuing to consider the intraoral components in the design criteria, to insure that the two parts are compatible when the design is complete. The design of the intraoral part does not meet these physiological guidelines in this prototype.

Currently, we know of four types of extendable mouthsticks that have been developed. One incorporates a rack and pinion arrangement which is activated when the user protrudes or retrudes his jaw [1]. This allows for an extension of only 1.5 centimeters. A second mouthstick is of the piston and cylinder variety. It is extended and retracted by the user puffing and sipping. The friction between the piston and cylinder is relatively high, thus making it difficult even for a person with normal respiratory function to operate, much less a person with respiratory problems. A third type of extendable mouthstick is extended by the user "hooking" a clamp fixed on the extendable shaft onto an environmental object, and then pulling [2]. Friction is present between the telescoping tubes, thus the desired position of the mouthstick is maintained. This design is lacking for two reasons. First, not all user's have the required mobility to operate the mouthstick and second, the time that it takes to change the length of the mouthstick is long. Lastly, a tongue activated, electric motor driven extendable mouthstick has been developed by Cloran [3].

## METHODS

We have pursued an extendable mouthstick powered pneumatically for the following reasons. 1. If operating pressures are maintained at appropriate levels, pneumatics offer a very safe power source. 2. A wide range of mouthstick forces are available by simply changing the operating pressure. 3. The time response of the prosthesis is variable, simply by adjusting the gases' flow rate. 4. The gas we have been using is air, which is easily available. 5. The actuators (AIRPOT®[1] cylinders) are low cost, light weight, and offer a wide range of extension lengths.

### DESIGN DESCRIPTION:

Gas is used to displace a piston contained in a cylinder. A three way valve is incorporated such that when a person bites, the mouthstick extends; when the individual decreases his/her bite force, the stick retracts. The retraction is caused by a spring. The main feature of the design is using a three way valve to control gas flow to and from a pneumatic cylinder. The pneumatic cylinder is manufactured by AIRPOT® and is commercially available. The AIRPOT® cylinder is critical to the design for the following reasons.

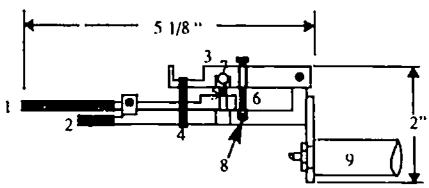
1.) The tolerances between the piston and cylinder are very high, thus allowing minimal gas leakage when the piston is being displaced (mouthstick extending).

2.) The two major components of the AIRPOT® are a cylinder made from pyrex® and a carbon piston. A very low frictional force is present between the carbon piston and the pyrex® cylinder, thus the operating pressure of the gas can be low (5 psi). Low operating pressures are advantageous because it results in minimal gas leakage and it allows for a safer

[1] Airpot Corp., 27 Lois St., Norwalk, CT, 06851

operating environment. The AIRPOT® comes with a rubber outer sleeve to protect the pyrex® glass.

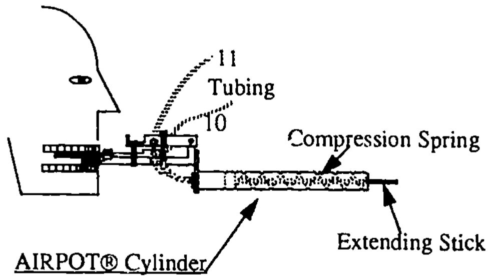
The three way valve is activated by the user's bite force. By changing the applied biting forces, the valve acts in such a way as to squeeze gas carrying tubes closed or allows them to open. A schematic of the valving unit is shown in Figure 1. When the unit is first placed in the mouth, it is situated as in Figure 2 (call this position #1). The rubber band supplies a compressive force between members 2 and 3. The area of contact between these members is at the point where the screw through member 3 makes contact with the tube passing through member 2, thus causing the tube (tube #10) to be compressed shut. This tube connects the gas supply to the AIRPOT® cylinder. The tube (tube #11) venting the AIRPOT® cylinder to the atmosphere is still open. This tube becomes squeezed closed when the user applies enough bite force for the screw contained in member 1 to compress tube #11 (position #2). When the user applies enough bite force to overcome the force supplied by the rubber band, member 3 pivots, thus allowing tube #10 to open (position #3). Now, gas flows in to the AIRPOT® cylinder from the gas supply and thus causes the mouthstick to extend. To retract the mouthstick, the user decreases his/her biting force to obtain position #1. Now the gas supply is cut off and a compression spring located in the cylinder acts on the piston, thus retracting the mouthstick. Any intermediate mouthstick position can be obtained by the user toggling between positions #1 and #3 and then going to position #2 which will retain the current position. A valving system schematic is given in Figure 3. The valving unit was placed outside the mouth for safety considerations.




1. Member #1
2. Member #2
3. Member #3
4. Rubber Band
5. Set Screw (rounded end)
6. Screw (rounded end)
7. Hole for Exhaust Tube
8. Hole for Inlet Tube
9. AIRPOT® Cylinder

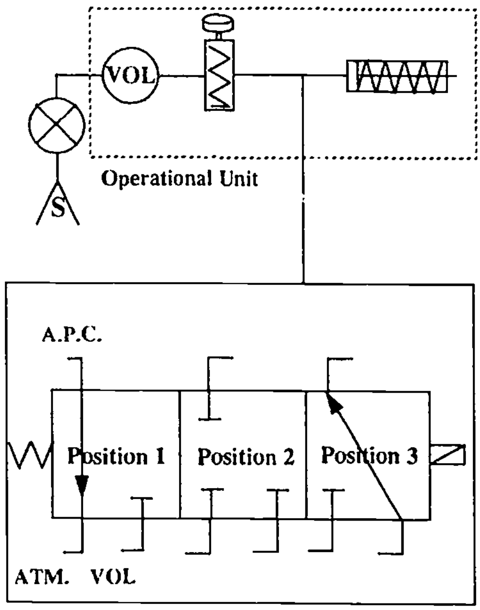
**FIGURE 1**

**Schematic of the Bite Operated Valve of the Extendable Mouthstick Prototype**




10. Tube from Air Supply to AIRPOT® (through hole 8)
11. Tube from AIRPOT® to Atmosphere (through hole 7)

**FIGURE 2 - Schematic of Operational Mouthstick**




ATM: Atmosphere
A.P.C.: Air Pot Cylinder
VOL: Air Supply Tank

FIGURE 3 -ANSI Schematic of Valving System

## RESULTS

We have a working prototype along with a portable air supply that we have been testing. We plan on testing the mouthstick in a clinical setting in the near future. During and after testing we will look at the device's functional short comings and make the appropriate adjustments. Also, we will try to determine the social acceptability of the device under its present design and looks. We realize that the device certainly should be made smaller, better packaged, and more aesthetically pleasing to better serve the user.

## DISCUSSION

The design meets a criteria known as Extended Physiological Proprioception (EPP) in rehabilitation engineering/robotics. This means that the user has force feedback when using the device and there is a direct correlation between bite force and the length of the mouthstick. A prosthesis having this feature is more natural to use.

As mentioned previously, we have been focusing on the design of the body of the mouthstick and not the intraoral portion nor the accessory tips. After the extendable portion is deemed satisfactory, we hope to investigate the design of the intraoral portion so it is physiologically compatible with the mouth and dentition. Such considerations include not having forces upon erupting teeth, making sure the mouthpiece contacts all fully erupted teeth, having the prosthesis stabilized by opposing dentitions when the jaw is very near its physiologic rest position, making sure the material used has various properties, making the design such that the user can talk, swallow, and wet his lips when the mouthpiece is in place, etc. For a more extensive discussion and a complete list of guidelines for mouthstick design see references 3-5.

Work has been done by Cloran, Kozole et al, Lutwak [i.e., 2,3,6] and others on accessory tips that the user can change independently. The accessory tips are usually placed together in a docking station where the user can place the mouthstick when not in use. The coupling of the accessory tip with mouthstick end is usually caused either through friction or magnetism. Such accessory tips may include a rubber ended tip, hook, paintbrush, pencil/pen holder, eraser, etc. This idea of a docking station arrangement will eventually be incorporated into our system in order to make it more complete. Our goal is to make an attractive, socially acceptable (meaning deemed usable by the user), and safe pneumatic powered extendable mouthstick with a variety of accessory ends which the user can change independently along with a docking station where the user can independently place the mouthstick when not in use.

One design issue which has not been established, is that of the gas supply. Possibilities include regulating air from a small tank filled with compressed air (this is the set up used for the prototype), using a small air compressor with tank, or using carbon dioxide containers with an air pressure regulator. The ideal gas supply would be a small and quiet pump capable of delivering 5 - 30 psi output pressure; however other sources may be more appropriate.

Finally, before the device can be considered for commercial production, we need better estimates of user acceptance, production costs, and market size.

**Acknowledgments**

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S. Scott Stroud
Applied Science and Engineering Laboratories
A.I. duPont Institute
P.O. Box 269
Wilmington, DE 19899
U.S.A.

Email: stroud@asel.udel.edu

18.2

# SAFETY CONSIDERATIONS FOR REHABILITATIVE AND HUMAN-SERVICE ROBOT SYSTEMS

H.F. Machiel Van der Loos*†, David S. Lees†, Larry J. Leifer†

* Rehabilitation R&D Center
Department of Veterans Affairs Medical Center
Palo Alto, CA

† Department of Mechanical Engineering
Stanford University
Stanford, CA

## ABSTRACT

The safety of electromechanical systems used in rehabilitation depends not only on the quality of the device, but also on the quality and degree of integration of the user interface. In the small, young and underfunded field of rehabilitative robotics, the complexity of the systems has forced pioneers to concentrate on partial solutions. Casualties include interface design, interface integration, and a system-oriented design approach. Safety, if viewed as the system's resistance to harming the operator as well as the environment and the robot, is the quality globally sacrificed.

## BACKGROUND

The design of equipment for rehabilitation is constrained largely by cost. The lack of resources available for the design of any one device is not due to overall market size (which is large), but rather to the highly individualized nature of the disabled population. Resources, therefore, are spread over a large variety of solutions, making each individual market small.

The result of this fragmentation is that most rehabilitation industries can not mature properly. The exceptions are those rehabilitation niches which do have a large market, such as wheelchairs, and those which rely predominantly on industrial or consumer-grade components or equipment, such as environmental control units and some software programs. For these areas, open-market forces, standards and regulations benefit the rehabilitation area by ensuring quality. For smaller domains, such as adaptive access devices for computers, augmentative communication aids and rehabilitative robotics, evolution is slow due to the lack of resources, which limits design iteration and perfection. Along with the small markets, the lack of available investment capital conspires to keep component and product quality lower than for consumer products comparable in complexity. Casualties of this generic problem are product reliability, performance, and safety.

## PROBLEM STATEMENT

Safety is a multi-faceted design consideration. It must explicitly influence all aspects of any device: the electronics, geometry, materials, cabling, software, and user interface. In rehabilitation, such a systems approach is crucial due to potential life-threatening consequences of system failure and malfunction. The more complex the system, the more important it is to design in the safety features. Cost constraints, however, tempt designers to be content with a minimally functional and thereby unsafe system. For rehabilitative robots, Asimov's three laws of robotics [1] provide a high-level checklist for designers to follow.

The cost of industrial robots (which start at US$50,000) is considered prohibitive by much of the rehabilitative robotics community. Certain R&D groups have developed their own robots to undercut the prices of industrial robots while delivering appropriate levels of quality and performance (see [2] for an overview). Development times have been long, costs have drifted into the industrial robot range, and some systems have failed due to the low level of performance for the cost. The design approach and the level of attention to safety vary from system to system. The field of rehabilitative robotics is still looking for a definitive solution.

Another approach by research groups has been to re-engineer and enhance existing robot systems, benefiting from existing technology while concentrating development effort where the application mandates. For example, the MASTER Project uses a re-engineered and enhanced RTX robot [2] and the VA-Stanford robot DeVAR uses a modified PUMA-260 robot with the user interface on a separate computer [3]. The PUMA is the most expensive industrial robot of the three, and predictably the most robust as well.

Which of these systems embodies sufficient levels of attention to safety to be used in the rehabilitation domain? Are industrial standards enough? Are they too stringent? Are they appropriate in scope for non-industrial applications?

## APPROACH

In industrial robotics, the approach to safety has been to cordon off a robot workcell from people, and to shut down a robot in case of intrusion. Accidents have occurred when security systems are intentionally thwarted, or during robot reprogramming, when technicians are allowed inside the robot's workspace. The user interface of these robots should be blamed for the accidents, not the arm itself, since the interface did not have provisions for all operating circumstances that could have been anticipated, including minor fault correction and reprogramming. Viewed in this way, the designer violated Asimov's Laws.

Sheridan and Ferrell argue that a 'man-machine system' such as a robot includes the user as part of the system [4]. The interface can better integrate all operating modes, therefore, if they are considered beforehand as part of a whole. Suchman points out that humans tend to view systems that exhibit *certain* human characteristics (e.g., following rules, answering requests) as exhibiting human behavior in *all* situations [5]. Such extrapolation may cause a robot system to be perceived as safe while in fact it can be dangerous if used in ways not anticipated or constrained by the designer. It is thus incumbent on the designer to make the user interface itself convey the limits as well as the capabilities of the robot.

The concepts of a tool (such as a human-service robot) being 'ready-to-hand' and 'present-at-hand' [6] are useful when discussing interruptions in normal use (breakdowns). A tool in use is 'ready-to-hand' since it is taken for granted (ready) to let the user perform a task. In a breakdown, its presence comes to the fore. The use of the tool now becomes the task, since the tool needs fixing or adjusting. A successful interface will give the user access to information necessary for diagnosis and repair, perhaps by modifying the interface itself. If such provisions do not exist, then safety is compromised, since the user has no recourse to proceed with the original task.

In complex industrial process systems, such as power plants, the user interface can impede correct diagnosis [7]. The information available in the control room may give a true but too complex image of the system (e.g., one hundred pressure and temperature gauges). The presented information must be consistent with the plant's process goals, not with the process elements [8]. Real-time diagrams showing conservation of energy and mass make it easy to locate hot spots and leaks through discontinuities in the display. An operator can then use the plant's valves and bypasses to correct the overall problem.

A systems approach is crucial to proper design, and must include the interface and user. Furthermore, the interface must concern itself predominantly with the tasks the user wishes to perform, not the attributes of the device itself. If an interface contains provisions for breakdown-management, then safety concerns are more likely to be folded into the context of normal operation, not viewed as an aberration.

## IMPLICATIONS

The designer of a human-service robot has to spend as much effort in making the hardware robust as making the interface complete. The following points address the problem from different angles:

- Safety has to be viewed not only in terms of the traditional 'mean time between failures' (MTBF) but also in mean-time between breakdowns (as defined above). During a breakdown, the robot, not the task at hand, becomes the object of the operator's attention. Mechanisms should exist to correct, bypass, reverse, or eliminate the fault condition. These should be built into the interface as well as designed into the hardware, and should include redundant communication channels, call buttons for outside assistance, and debug modes to diagnose the specifics of the fault.
- The interface designer must anticipate the most common faults (e.g., the robot collides with an object) to allow the operator to deal with them gracefully. As a corollary, the high-level software (task execution) must let the operator interact with

the next lower level of software (motion-commands), as well as the lowest level (real-time control). Such layer-to-layer shifting is essential for debugging and breakdown management.

- The designer has to assume that the robot will be used for tasks that are unfathomable at the time of design. Winograd asserts: "The most successful designs are not those that try to fully model the domain in which they operate, but those that are 'in alignment' with the fundamental structure of the domain [9]." For example, if a robot will be dealing with cups of fluid, the gripper must at least be splash-resistant, even if the 'Drink' program does not involve pouring.
- Safety must permeate all aspects of the hardware and software design. A hardware defect should not be corrected by a software fix. If the gripper of a human-service robot has sharp edges, then it is not appropriate to program the robot to stay far from its user. Such a design decision invites abuse and a corresponding reduction in safety.

## DISCUSSION

Given the embryonic nature of rehabilitative robotics, safety has taken a back seat to functionality, features, and the proof of system feasibility. Even discussions of system design have rarely included safety considerations [10]. In the automotive industry, advertising has not always focused on safety concerns, supposedly out of fear that potential consumers would be turned away by mere mention of the topic. It is only recently that vehicles contain substantial safety provisions (through regulation, mostly) and that the topic of safety is actually a major selling point for new cars. Is a similar effect occurring in rehabilitative robotics?

Telerobotics, of which rehabilitative robotics is a subclass, distinguishes supervisory control from direct (master-slave) control. In the former, the goal is the fidelity of the task description and execution; in the latter, fidelity of the sensorimotor aspects of remote operation. Each mode has distinct advantages and is appropriate in different situations. The degree of autonomy of the device to respond to local conditions is another important factor. A design may include reflex or control loops that do not include and may be hidden from the operator. In rehabilitative applications, safe operation means matching the user with a suitable control mode and with the appropriate level of local autonomy. Important factors in making design choices are the user's level of physical ability, control of body motions, and cognitive ability.

## ACKNOWLEDGMENTS

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## ADDRESS

H.F. Machiel Van der Loos
Rehabilitation R&D Center
Veterans Affairs Medical Center
3801 Miranda Ave. #153
Palo Alto, CA 94304-1200

Office: 415-493-5000 #5972. Fax: 415-493-4919

# Bilateral Control in Teleoperation of a Rehabilitation Robot

**Tariq Rahman and William S. Harwin**
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

## Abstract

*This paper describes ongoing work in the area of rehabilitation robotics interface design. Some issues addressed that are considered important in improving man/robot interaction are, proprioceptive feedback, constrained and unconstrained force reflection, bilateral (power and information transfer) control. A single degree of freedom shoulder input device that measures and conveys force and position information has been constructed and connected to a desktop robot prototype that has force and position sensing capabilities. It is hoped that by improving the control system in contact and non-contact manipulation the interface can be made more natural, thereby making a rehabilitation robot more effective.*

## Background

Of primary concern in rehabilitation robotics is the relationship between an operator who has physical limitations, the robot, and the environment. Just like its natural counterpart, a robotic arm, in order to perform a wide array of tasks, needs to have a teleoperation mode. This places control of the arm with the human user at a lower level. The resulting increase in control, however is gained at the expense of mental effort put forth by the user. Given that it is desirable to utilize human control capability, this paper addresses specific issues that help to reduce the concentration required of the disabled user who operates a 6 D.O.F. robotic device.

Rehabilitation robots being used today in laboratories and clinics are slow in performing relatively simple non-programmed tasks such as picking and placing a peg in a hole, or drinking. Part of the problem is not having enough inputs to control multiple degrees of freedom, consequently having to switch modes. The other area of concern is reliance on visual and incidental feedback alone.

Considerable work has been done in the area of prosthetic arms to improve the interface between the wearer and the arm. Simpson [1] developed the idea of extended physiological proprioception (EPP) whereby the person has a direct 'feel' for what the arm is doing, through the interface. An EPP controller was designed [2,3] and was shown to be an improvement over velocity controlled electromygraphic prosthetic arms, however, control is at the joint level which limits the number of degrees of freedom that can be successfully controlled. Furthermore true EPP in the sense of an 'unbeatable' [1] system was absent. Abul-Haj and Hogan [4] used impedance control to illustrate the importance of controller architecture in enhancing an amputee's functional capability. The ideas of EPP and impedance control have similarities in that both stress the use of natural control modes in the design of interface devices.

Kazerooni [5] stressed the bilateral exchange of both information and power signals between the user and manipulator, whereby human power is amplified by an external source while control remains with the human. The bilateral control problem increases in complexity when the user is disabled, with a limited number of input signals. Force reflective manual input devices, such as those at JPL [6] have been developed but none have looked at alternate control sites such as the shoulder or head.

## Problem Statement

The aim is to design an 'unbeatable' servomechanism [7] that links multiple degrees of freedom of a robot to limited number of human inputs in a way that provides the human with proprioception that would make the robot act as an extension of the user. This would involve unconstrained manipulation as well contact tasks.

For C4, C5 level quadriplegics intact shoulder function provides a command source [8] for a manipulator that is intuitive and lends itself readily to EPP principles. The goals of the work are twofold, a) to design an effective 2 D.O.F. shoulder input device that controls both force and position of a robot, b) to research and develop control strategies for manipulation that explore issues related to EPP and impedance control in unconstrained and constrained manipulation, with a handicapped user in the loop.

## Approach

A single degree of freedom shoulder input device (master) has been constructed. This controls a 1 D.O.F. manipulator (slave) capable of transmitting force (torque) and position (velocity)[2]. The following

1. The term 'unbeatable' describes an inflexible link between input and output, where the input cannot overshoot the output and vice versa.
2. By starting with a 1 D.O.F. system, problems associated with crosstalk and coordination can be avoided.

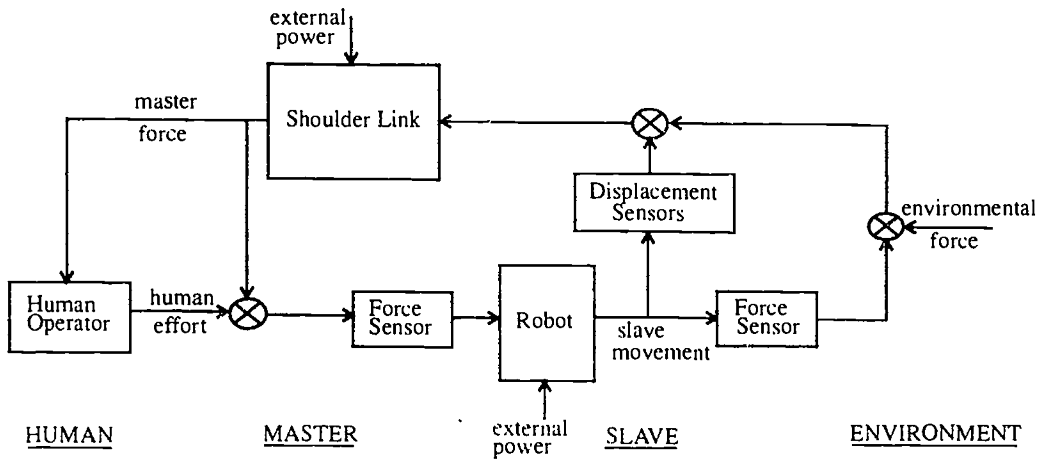


FIGURE 1. A general diagram showing bilateral exchange of power and information signals between the shoulder link and the robot

control schemes have thus far been implemented,

a) Slave velocity, controlled by master position
b) Slave position, controlled by master position
c) Slave velocity, controlled by master force
d) Bilateral control of both force and position between master and slave (fig. 1)

The different control schemes will be used in a 2 D.O.F. system and assessed based on criteria such as, time to complete task, forces exerted, ease of control, mental effort, and quality of execution.

*Design*

The shoulder link consists of a molded harness that is padded and attached to the shoulder by velcro straps under the armpit and around the torso (fig 2). The end of the shoulder link is attached to the harness through a ball and socket joint. A full bridge strain gage transducer is mounted at the tip of the link and measures shoulder protraction-retraction force. The linear shoulder motion is then transformed to rotary motion through a universal joint. The center of rotation is a shaft that sits inside a magnetic particle brake, capable of applying a braking force to the shoulder. The angular displacement of the shaft is measured by a potentiometer. The entire master link is attached to an adjustable wooden chair.

The master link is connected, via a PC, to a 1 D.O.F. robot that sits atop a table in front of the user. The robot is driven by a DC motor and rotary motion is transformed to linear motion by a rack and pinion. A full bridge strain gage transducer at the link tip monitors environmental force.

The hardware controlling the system consists of a 12 bit, 8 channel A/D card; the slave link control card, which uses pulse width modulation and performs PID motor control where position feedback is from a digital encoder. The magnetic brake is also activated by PWM, in accordance with the software control scheme used.

The single degree of freedom system will be extended to two D.O.F. The shoulder link will be a pantograph type which would allow the actuators to be placed at the base.

## Implications

Extended physiological proprioception implies there is a mechanical link between input signal and response, whereby the two are coupled in terms of forces, positions, velocities and accelerations. In a prosthetic arm this coupling can be realized via a Bowden cable, however a robot, besides being remote has more degrees of freedom which make mechanical linkages impractical. This work attempts to artificially create conditions of mechanical coupling that provide 'feel' for what the arm is doing. This proprioceptive sense is important in performing contact tasks such as writing on a table which requires more force control, or moving the hand in space which has more of a position (or velocity) control component. It is unlikely that in either case it is exclusively a force control or position control problem, rather a combination of the two.

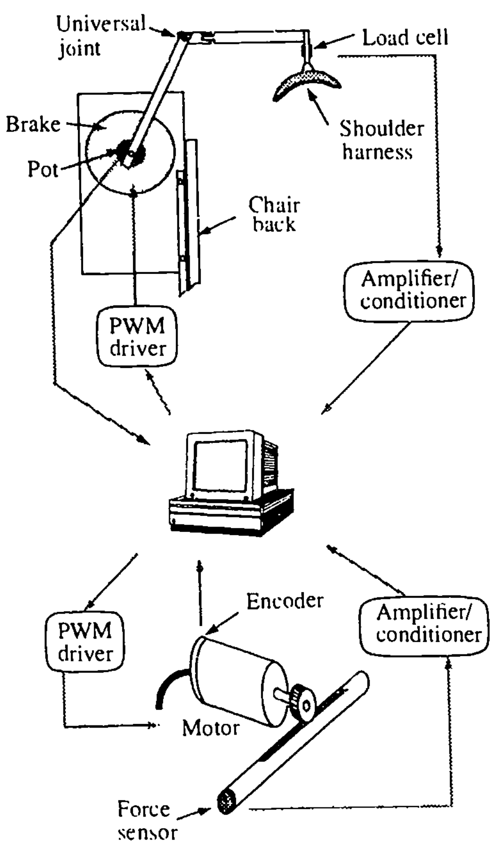


FIGURE 2 Diagram of completed single degree of freedom master/slave system. Control is from PC

## Discussion

Preliminary tests conducted on able-bodied subjects indicate preference of position control over velocity control which is in line with established principles of EPP [3]. The drawback of using position control at the shoulder is the relatively small range of acromal movement. This translates to limited movement in cartesian space of the robot, although control of gain can be made accessible to the user thereby yielding greater movement. Bilateral force/position control is thought to convey increased kinesthetic feedback to the user. This control scheme is presently being implemented on the existing system.

The actuators for the master link presently use magnetic particle brakes which have a fast response time and are safer since they only apply a damping force. In order to realize full EPP at the shoulder, however, it might be necessary to use active elements such as electric motors to provide complete dynamics to the user.

In order to make a rehabilitation robot more effective and acceptable the man/machine interface has to become more 'natural'. This can be done by providing the user with a sensation of forces and resulting motions at the robot end. One way of accomplishing this is through EPP, which attempts to establish a physical link between the two.

## Acknowledgment

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Tariq Rahman
Applied Science and Engineering Laboratories
Alfred I. duPont Institute
P.O. Box 269
Wilmington, DE 19899
(302) 651-6831
rahman@asel.udel.edu

18.4

# A COMMAND MONITORING SYSTEM FOR THE MANUS ROBOTIC ARM

John W. Bishop, Geb Verburg, Morris Milner, Martin Mifsud
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road, Toronto, Ontario, Canada

**Abstract:**

The MANUS robotic arm is a wheelchair mounted manipulator arm designed for use by persons who are serverely physically disabled. These users typically have limited control or strength of their arms and hands necessary to complete tasks of daily living.

The manipulator allows the user direct end-point control of arm movement by translating commands for position translation or gripper orientation in terms relevant to the user. In this research project, the robot is being evaluated in independent living , vocational and school environments. A computer controller signals, and calculates bounds of operation, valid zones and positions of the arm. A monitor specifically developed to record these commands was designed and implemented to analyze actions performed with the manipulator arm. It's features and capabilities are described.

**Introduction:**

Objectives of the MANUS (1) study include:

(1) the evaluation of the usefulness of a manipulator arm for an individual with restricted hand movement and who uses a powered wheelchair;

(2) a study of how the arm is used by analyzing specific activities of daily living such as eating, pouring a drink or moving objects (e.g., a book, opening a door, etc.);

(3) identification of potential enhancements to the operation of the arm pertaining to:
- arm design (parameters such as resolution of movement)
- user interface
- speed

(4) analysis of arm utilization for the identification of common control sequences that will allow the implementation of a degree of task control in addition to direct control of the MANUS.

To perform the latter analysis required specific information detailing the commands given to the arm. A video recording system operated by a microcomputer device was designed. The criteria for such a monitoring device include:
- command inputs to the arm sampled every 40mS minimum while the arm is being operated;
- events captured and stored for later analysis.
- recording of both manipulator arm actions and command signals issued to complete the tasks.

synchronized recorded information to correlate task activities. An audio track on the video tape provided a convenient method for storing the information captured while synchronizing the command data and video images.
- a visual record of the MANUS actions and audio record of user comments and ambient sounds. A stereo handycam was used to capture these.

The arm is controlled through a 4 x 4 keyboard or an analogue joystick. Several modes controlling arm position, gripper orientations, etc., are displayed on an LED display.

**Design Objectives:**

In order to obtain the command information described, it was necessary to construct a data logging system to:
(1) monitor and capture commands;

(2) convert this information to a form that can be recorded on video tape;
(3) control and monitor the video camera and supply feedback to the user regarding recording status (e.g. end of tape); and
(4) optimize tape usage.

**Design:**

The design of the data logging system is based on a MC68705R3 microcomputer. Keyboard inputs to the monitor's microcomputer are conditioned, for compatibility, and scanned by the controller using a simple four input and four output arrangement. Each of the four lines is strobed and read in a period of 5uS every 40mS. Since this is too fast for reliable polling by the microcomputer, additional hardware asynchronously stores the keyboard closures in a 4 x 4 RAM.

Joystick inputs to the controller vary among 0 and 5VDC and require minimal conditioning. The design also protects the microcomputer against input voltages outside the operating range.

The mode display consists of a 5 x 7 LED array to display symbols indicating the arm's operating mode. Monitoring four of these LED's provide 16 numbers to uniquely identify the mode. These signals and the panic button signal connect to the microcomputer via opto-isolators.

To control and monitor the handycam, the microcomputer activates a solenoid positioned to press the record button on the camera. A photo transistor positioned over the record LED on the camera monitors status, and is interpreted by the software. The user receives audible messages and warning beeps on the camera's status.

Since the study involves timing measurements of the commands issued, a real time clock provides 10mS resolution. The current time is recorded and combined with the input data during each input event. A dual serial port connected to route the data from the monitor, connects a type 202 FSK modem built into the monitor to the handycam audio channel. The other serial port is used in the playback process to download the data over an RS-232 link to an IBM type personal computer.

Detection of new keyboard events creates a data packet containing input and timing information. This formatted packet contains a header indicating packet type, and a checksum for error detection.

A 202 type modem is used to modulate data. The capacity of the audio channel on the handycam is limited to 1200 baud. Since the potential information rate resulting from changing inputs is higher, information may overflow when data changes at a sustained rate greater than 6 events per second. To protect data validity, information overflow is flagged as part of the data packet definition.

Memory usage of the microcomputer is optimized so that all available memory is configured as a FIFO buffer to queue data for transmission to the handycam. Information stored in raw hexadecimal format is converted to ASCII format during the playback process and downloaded to the PC at 9600 baud.

A second packet type is created when no new data are detected after 5 seconds. This contains a 'user identification text string' to facilitate identification of the user during analysis. Detecting no new data over a two minute period causes the microcomputer to command the handycam to switch off to extend the usable time for a 2 hour tape and to optimize the editing process. New data causes the creation of a new packet, buffered until the restart of the handycam, and then transferred to tape.

The microcomputer is also responsible for camera supervision. Delayed operation occurs during camera activation or deactivation due to camera constraints. Audible tones are therefore used to signal operational status including unsuccessful operations after the timed period. The handycam also provides an end-of-message warning five minutes before tape end by flashing the REC LED and another audible message.

**Methods:**

Seven adults and five children have used the arm for assessment of training in the laboratory or in their independent living, working, hospital or school environment. Questionnaires and observation scales are being administered with each subject. The MANUS robot and task recording system (i.e., video camera and monitor) are mounted on each participant's wheelchair.

**Results and Discussion:**

Much data about the types of activities that can and cannot be performed the MANUS have been collected. The list of feats performed continues to grow and includes household, grooming, office and maintenance tasks.

Information has been collected about the decisions to accept and reject this manipulator technology. The primary decision is based on the trade-off between benefits and efforts, on the choice between what the arm can do for the user and how much time and effort and inconvenience it costs to do it as opposed to asking someone else for assistance. Practical limitations such as accessibility issues, i.e., door widths, or control input options are important considerations. This study is helping to determine prescription criteria based on personal characteristics, needs and user environment.

Data from the monitor described above are used to identify common actions performed by different MANUS users. These common sequences are found in two ways: usually by viewing the video tapes and coding the actions according to properties of a unique coding system developed in this project adapted from Van Lunteren et al (2), and the Method Time Measurement System of hand and arm movement analysis pioneered by the Gilbreths' (3). The annotation scheme records the object, action, MTM element, location and success of the action.

By contrast, the second analysis of common command sequences is entirely computerized. Here the computer seeks through all commands and generates a list of single commands, lists of pairs, triplets and common quadruplets. The numerical sequences are coded with mnemonics that signify the arm movement and combinations with a frequency of occurrence higher than 5 or 10 (or some value determined by the size of the file and the variability of the actions). These are pulled out and played back on the arm to observe the movement found. If this movement is recognizable and its automation is likely to save the user time this command sequence is recommended as a potential sub task to be programmed.

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The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, Ontario,
Canada M4G 1R8

# A Pneumatic Actuation System for a Wheelchair-Mounted Robot Arm

**Mohamed Ouerfelli[1], William Harwin[2] and Vijay Kumar[3]**
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

### Abstract

This paper describes a pneumatic actuation system for a low-cost, compliant, wheelchair-mounted robot arm for motor-disabled children. The system consists of two Flexators[4] [1] and a four-bar transmission linkage. Experimental results on the dynamic performance characteristics of the actuator are presented. The design of the transmission linkage is described. Finally, the on-going and future work is discussed.

### Introduction

The Flexator is a tubular chamber built from conventional fire hose (details are found in [1]). These actuators may have several application such as the esco skeleton demonstrated by Fluck and Hennequin[4]. Similar actuators discussed in [2] and [3] are, respectively, the pouch actuators and the braided pneumatic actuators. The Flexators are simple, inexpensive and safe. However, the absence of friction, and the high strength to weight ratio are the properties that most motivated the authors to consider these actuators. Previous analytical and experimental work has been done on the dynamic response of a mechanical system driven by the Flexator [1]. However, the experimental results for the Flexator operating between two steady state conditions and the thermodynamic model show a discrepancy of 50%. The difference was attributed to the assumptions made to simplify the model in which heat transfer and friction losses in the system have been neglected [6]. In this work, a simpler system consisting of just the Flexator is considered in order to obtain a better understanding of the dynamic performance of these pneumatic actuators.

### Dynamic Response of the Flexator

In order to obtain the dynamic response for the Flexator, an experimental test-bed, as shown in Figure 1, was built. The Flexator works against a cantilever beam and the bending stress is measured with a strain gage. The response to a 20 psi step input is given in Figure 2 from which the time constant was estimated to about 198 milliseconds. However, a different step amplitude (10 psi) led to a different time constant (180 milliseconds). This is indicative of the nonlinear behavior of the actuator. Experimental observations tend to indicate that the step response will be slower with increased step pressure. It is also important to note that the speed of response decreases dramatically as the volume of the transmission lines and the actuator is increased [7].

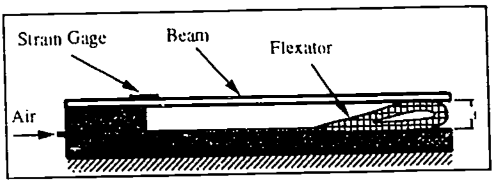


**Fig.1:** Experimental Set-Up for the Flexator

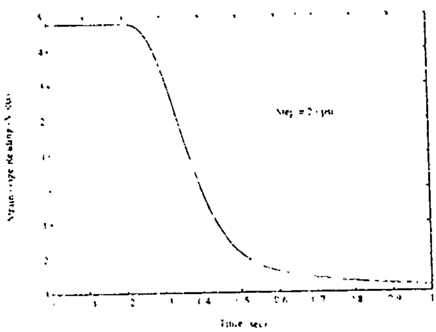

**Fig.2:** Step Response of the Flexator

The conditions in this experiment are representative of those expected in force control. When a manipulator makes contact with the environment and the contact force is regulated, the supply pressure will be controlled while the variations in position will be minimal. Therefore, we expect a force control bandwidth of approximately 1.0 Hz for a small-signal response.

The static response characteristics of the actuator are shown in Figure 3 for different geometries. The input to the actuator is the supply pressure while the strain gage measures the output force. In changing d, the distance between the beam and base plate, we simulate changes in the position of the robot link. It is worth noting that for a given value of d, the pressure-force characteristics are linear (as in conventional,

[1] PhD candidate, University of Pennsylvania

[2] Director of Rehabilitation Robotics, ASEL

[3] Assistant Professor, GRASP lab, University of Pennsylvania

[4] Flexator is the registered trade name of the Airmuscle Limited of the 12 Orchard Close, Cranfield, Bedford, MK43 0HX, England and is protected by the US Patent number 4, 944, 755

single-acting pneumatic cylinders). Further, as d increases, for the same input pressure, the effort (or the output force) decreases. While it is possible that the characteristics at much higher pressures are different, we believe that this is not the case. If the displacement of the robot link (or in this case, the flexure of the beam) is small, we speculate that the pressure-force characteristics are linear throughout the operating range (0-80 psi). Future experiments will be conducted to confirm this.

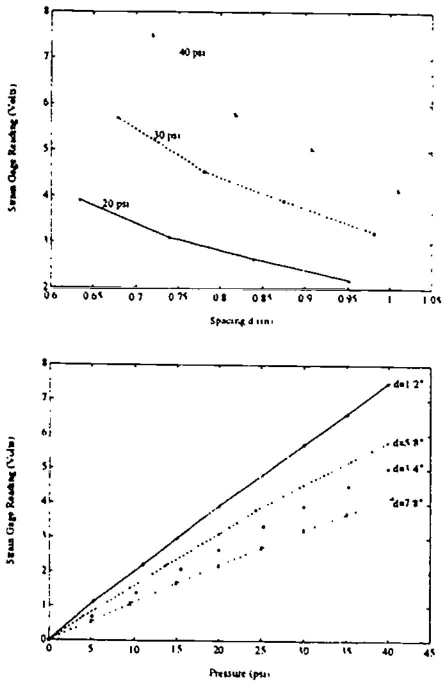


Fig.3: Strength Characteristics of the Flexator Actuator

### Thermodynamics of the Actuator

We have built another test-bed (shown in Figure 4) to validate the thermodynamic model first proposed in [1] and [5]. This set-up allows us to easily measure the pressure, temperature, and volume of air in the Flexator. The experiment will be carefully conducted to insure that heat transfer is minimal. Results will be published in a forth coming paper.

### On-going and Future Work

The transmission linkage shown in Figure 4 is a four-bar linkage with four rotary joints. The linkage is used to transmit power from a doubling acting actuator (consisting of two Flexators) to a revolute joint. By changing the link lengths, it is possible to vary the input-output force characteristics. Given the characteristic curves for the muscle, the mechanism can be optimized for a desired output torque at the driving joint.

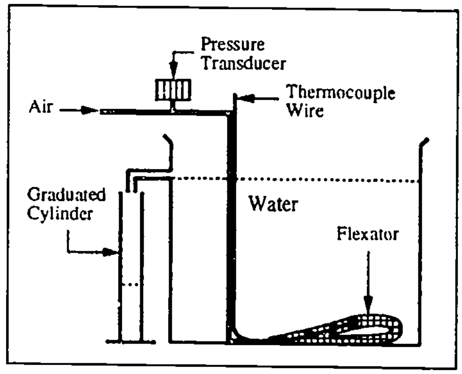


Fig.4: Measurement of Air Properties in the Flexator

We propose to experimentally determine a dynamic model for the configuration shown in Figure 5. This model will lend itself to control using Neural Networks.

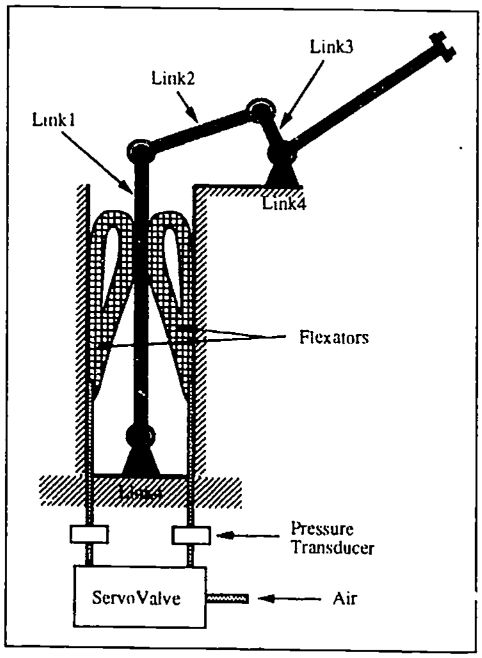


Fig.5: The Actuation System for a Double Acting Revolute Joint

### Conclusion

The approach taken in the different experiments discussed in this paper is simple and should enable us to better understand the behavior of these newly developed actuators. The Flexators, although somewhat slow in response, are attractive because of their low cost, low friction, and high strength to weight ratio and are ideally suited for the wheelchair-mounted robot arm.

**Acknowledgments**

The authors would like to acknowledge the support of the Nemours Foundation and the GRASP Laboratory at the University of Pennsylvania.

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**Mohamed Ouerfelli**
**Applied Science and Engineering Laboratories**
**A. I. duPont Institute**
**P.O. Box 269**
**Wilmington, DE 19899**
**U.S.A**
**Email: ouerfell@asel.udel.edu**

19.1

# THE SWING PACK
## A mobile wheelchair bag

Jorge E. Letechipia, Denise M. Fregede
Center for Applied Rehabilitation Engineering
Good Shepherd Rehabilitation Hospital
Allentown, Pa. USA

ABSTRACT

Commonly, wheelchair users store their personal items in a wheelchair bag located on the rear of the wheelchair. Because of this location, people with limited upper extremity strength and range of motion are often unable to retrieve items from their bags, limiting their independence. This paper describes the design, development, and clinical testing of a mobile wheelchair bag. The mobile wheelchair bag is a device to move the wheelchair bag from a stowed position behind the backrest to an accessible position along the side of the wheelchair, allowing the user to store or retrieve independently personal items from the bag.

INTRODUCTION

In the U.S., it is estimated that 1.2 million individuals use wheelchairs as their primary source of personal mobility (1).
Commonly, wheelchair users store their personal items in a wheelchair bag located on the rear of the wheelchair. This bag is suspended from the push handles where it does not interfere with propulsion, but also remains out of reach for many people. Because of this location of the wheelchair bag, people with limited upper extremity strength and range of motion are often unable to retrieve items from the back of the wheelchair and must therefore, rely on someone else to retrieve items for them. This situation prohibits independence for the wheelchair user for many vocational, leisure, and daily living activities.

At the Center for Applied Rehabilitation Engineering a mobile wheelchair bag was developed. The mobile wheelchair bag is an electro-mechanical device which is activated with battery power and moves from a stowed position behind the wheelchair backrest to an accessible position along the side of the wheelchair. With the bag at the side, next to the armrest, the user can retrieve or store items from the bag independently. By reversing the power, the storage bag returns to the stowed position behind the backrest of the wheelchair.

The purpose of this paper is to describe the methodology used to design and develop the mobile wheelchair bag as well as to present mechanical and clinical test results.

DESIGN AND DEVELOPMENT

The method used to design and develop the mobile wheelchair bag can be summarized in four phases.
First, the idea was presented to a group of experts in assitive technology. The group included physical occupational and recreational therapists specialized in the recommendation of a wide variety of assitive devices.
Second, the idea was presented to a group of wheelchair users. The group included individuals with active life styles operating in a wide array of environments.
Third, from the information gathered from these two groups, preliminary characteristics were established. These included:
adaptability to most brands of wheelchairs, load capacity of 10 lbs, self contained unit, easy to install and remove, easy to fabricate and repair, and cosmetically appealing.
Four, with these characteristics, the design group proposed, analyzed and tested different alternatives. Further analysis of the physical abilities of the wheelchair user and the limitation of space in the wheelchair determined the need of an electro-mechanical device to achieve the desired function.
The resulting device consists of a custom shaped bag secured to a rotation mechanism. The rotation mechanism consists of a rod secured in one end to the gearhead of a motor, and the other end secured to a base plate. The base plate holds

the mechanism and provides for the attachment to the wheelchair via a clamp. (Figure 1)

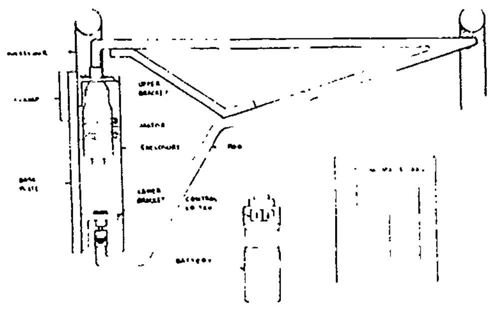

Figure 1

EVALUATION

Mechanical evaluation

Prior to conducting the clinical evaluation, tests were conducted to measure performance characteristics like: maximum load capacity, maximum incline under which the device will remain operational, and estimated battery life.
Performance test results indicated that the prototype complied or exceeded the initial characteristics, therefore the design team concluded that the device was ready for clinical evaluation.

Clinical evaluation

Twenty five units were fabricated for placement on the wheelchairs of 25 clients. The clients were wheelchair dependent with disabilities including cerebral palsy, traumatic brain injury, spastic quadriparesis, post-polio syndrome, hemiplegia as a result of cerebral vascular accident, and lower extremity paraparesis. These clients had active life-styles either working in the community or working from the home. The clients ages ranged from 27 to 77 years of age with the average age being 48 years.

Weekly reports of product performance and identification and documentation of any problems were kept on each client. Each client was responsible for keeping track of the number of times per day they used the mobile wheelchair bag, the number of times, if any, they needed assistance with the mobile wheelchair bag, any problems encountered using the mobile wheelchair bag, and comments regarding increased independence.

RESULTS

Information obtained from the client activity recording forms, showed that the average number of times the mobile wheelchair bag was used by all the clients was four times a day. Individually, the times clients used the bag ranged between one and fourteen times per day. Ninety-two percent of the clients indicated that using the mobile wheelchair bag provided easier access to their personal items, thereby increasing their independence.

The results of the mechanical evaluation were:
The maximum load capacity of the device was measured to be 12 pounds.
The mobile wheelchair bag when loaded with the maximum load of 12 pounds was able to operate at a slope of 5°. Using the average number of cycles per day (4 cycles, forward-backward motion of the bag), the estimated battery life when using the device under "average use conditions" is approximately 50 to 60 cycles , which translates to 12 to 15 days of operation on one battery charge.

DISCUSSION

Clinical results of the study suggest that the mobile wheelchair bag did increase the independence of the clients and the device proved functional during daily life activities.
These results strongly support the position that when designing new devices for the disabled individual, input from the end user as well as the expert professional are essential, prior to the development of the device.
In conclusion, the mobile wheelchair bag provides users with the opportunity to be more independent in their daily, leisure, and vocational activities.

ACKNOWLEDGEMENTS

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ADDRESS

Jorge E. Letechipia, MSBME
Center for Applied Rehabilitation Engineering.
Good Shepherd Rehabilitation Hospital
5th & St. John St.
Allentown, PA 18103.

# Objective Evaluation and Comparison of Crutch and Cane Tip Slip-Resistance

William English & Thomas Fetterman
Independent consultants

## Introduction

Injuries to people slipping and falling down on wet pavement is a much greater concern to those who use prosthetic walking devices than it is to the ambulatory public at large because these partially disabled ones tend to fall much more frequently, and a disabling fracture may immobilize a paraplegic altogether. Therefore, because of the greater need for slip-resistance integrity in walking aids for the mobility impaired, an objective aid was needed to facilitate development of safer products and to rank existing products for safety.

The primary disqualifying problem with the traditional static coefficient of friction testers is that they all have had a pronounced delay following the application of the friction material to the floor surface so that any moisture that might be present would be extruded out of the interface before the sliding force can be applied, so that artificially high readings always occurred. That was besides the problem of how to fit actual prosthetic devices to the various machines, which were intended primarily for evaluation of such sheet materials as leather or *Neolite*.

In response to this need for an objective slip-resistance tester a portable device was designed to measure the traction properties of various tips on a standard surface by applying an instantaneous load to a test tip by impinging it upon the surface at a selected angle of incidence. This mode of actuation eliminates the familiar "sticksion" problem arising from the long residence times prior to motion of the sensor across the test surface.

The new tester can be used to compare the slip-resistance performance of one tip to others or to measure the traction properties of crutch and cane tips on actual walking surfaces.

## Principle of Operation

A gas-actuated piston rod fitted with a test tip is set at a predetermined angle, and when actuated, the tip is pressed down onto a representative surface to determine whether it will slip at the preset angle of incidence.

The fluid-powered piston is hinged at its top end to a pivoted mast which in turn can be adjusted to varying angles to the floor. The angle of the mast is controlled by a jackscrew mounted between the mast and its base.

The device is actuated repeatedly at increasing angles of inclination from the vertical until a slip occurs. The tangent of the last angle before slippage occurs can be used to quantify the slip-resistance of the test tip on the floor surface under the prevailing environmental conditions. Real-world environmental contaminants such as water, oil or other lubricants may be applied to the interface between the tip and the floor to approximate actual use conditions.

Tests may be successively performed at incremental angles to determine the slip-resistance of the selected test tip, or a single "go/no-go" test may be performed at a datum angle to determine compliance with a given performance specification for floor slip-resistance, such as might be mandated under the new OSHA or ADA regulations.

The coefficient of traction for any test configuration can be determined by looking up the tangent of the least acute angle at which no slip occurred, according to guidelines published years ago at what was then called the National Bureau of Standards. For example, if the last angle at which no slip occurred was 26.5 degrees from the vertical, the coefficient of friction would be .50.

## Background of the Invention

Machines based on the instantaneous application of force at a specified thrust vector onto an actual walking surface were developed at the Veterans Administration, the first (an instrumented walking cane) having been described in a 1977 publication by Leon Bennett and Eugene Murphy.[1] The cane was fitted with a means to show the angle of incidence, and a force gauge measured the magnitude of the thrust vector.

This principle was refined in a laboratory cane tip tester (a variable incidence mast fitted with an articulated cane that was thrust downward at a predetermined angle by an electric solenoid) described in an unpublished 1984 report by Eugene F. Murphy.[2]

The problem with the instrumented cane was that the device was subject to operator-dependent variables that tended to bias the results, and evaluations were somewhat subjective. The solenoid-actuated cane tip tester removed the operator-dependent biases, but was not portable, and the spiked thrust action of the solenoid did not approximate human walking behavior.

The tester described herein is a refinement of the solenoid-actuated variable-incidence cane tip tester described by Murphy.

## Discussion

Foreseen uses of this kind of test device include the testing the slip-resistance of prosthetic walking devices, permitting its use both as a development tool in the design of improved prosthetic tips and also to evaluate their effectiveness on actual walking surfaces; or it can be used to determine the most effective of a series of tips under specified environmental conditions.

The device can also be used under these controlled conditions to substantially simulate the forces present when used by humans during the walking process. Velocity of the force vector is controlled by adjusting the fluidic pressure acting upon the piston, and after surface contact the applied force curve builds up smoothly in a manner not unlike human ambulation.

Furthermore, operation of the device is automated so as to remove such operator-dependent variables as variations in velocity of impact, magnitude of force or duration of force application. And its function is independent of gravity, facilitating testing on sloped surfaces without the necessity of re-calibrating the machine for use on a particular incline or ramp.

With adaptation of other tester "feet" to the end of the piston shaft, the invention also may be used as a slip-resistance tester for floors, and with yet another adaptation, it can be used to investigate the slip-resistance performance of footwear products on floors.

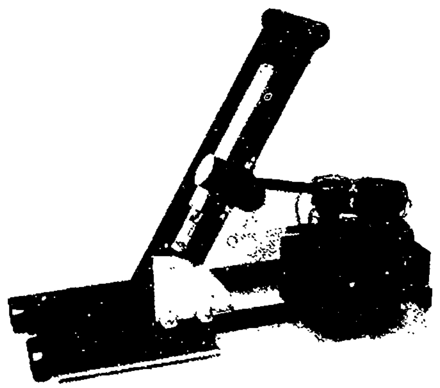

**Figure 1** The angle of inclination of the gas-actuated cylinder is controllable by an electrically-driven jack screw. Air pressure from a miniature compressor thrusts the piston rod downward at the preset angle, which is indicated on the protractor by a pointer.

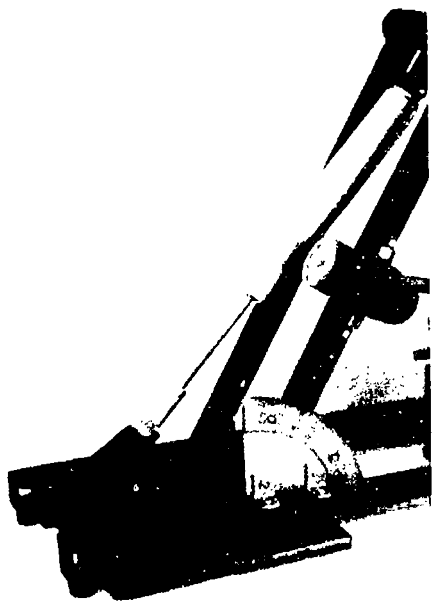

**Figure 2** If the angle of inclination from the vertical is sufficient to exceed the coefficient of friction of the test tip on the test surface, the tip slides across the surface, pivoting around its mounting axis at the top, producing an obvious slip.

Test Results

| | |
|---|---|
| Crutch tip #1 | .354 |
| Crutch tip #2 | .493 |
| Crutch tip #3 | .547 |

Table 1 The relative slip-resistance performance of three different crutch tips is compared on the standard reference surface wetted with deionized water. The performance spread is significant.

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## Acknowledgements

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William English
William English, Ltd.
3018 Hunt Road
Oakton, VA 22124

# GENERATION OF A DATA BASE FOR REASONABLE ACCOMMODATIONS

Charles J. Laenger
Kaiser Rehabilitation Center
Tulsa, Oklahoma

David D. White
Oklahoma Department of Human Services
Tulsa, Oklahoma

Abstract

Vocational rehabilitation professionals can generate a data base that will help the courts and lawmakers to develop fair and sensible rules for reasonable accommodations in the workplace. Consolidation and analysis of past successful cases can be made to determine cost-range-history for worksite modifications and disabled worker assist devices. A large compendium of cases could be made to present such data as disability vs. cost, disability vs. types of special equipment, disability vs. loss of floorspace, and other valuable information.

Such data would be very useful to employers for budgeting and planning; it would encourage clients and attorneys to pursue fair and reasonable compensation and accommodation. Ultimately, such data would help to create specific rules based upon the welcomed, but vague, Americans with Disabilities Act.

## Background

It appears that definitive laws and regulations regarding reasonable accommodation in the workplace will be developed in the courts through myriads of cases. Attorneys are preparing for confrontation, and employers are trying to prepare for compliance. Attorneys are contemplating awards, compensation and fees; employers are contemplating increased expense, decreased production and possible bankruptcy.

## Statement of the Problem

The American with Disabilities Act does not currently provide a clear definition of "reasonable accommodation" for disabled employees in the workplace. Understandably, employers are very apprehensive. Employers do not know whether worksite accommodations for a new paraplegic secretary will cost $100 or $10,000. Further, they have few professional resources that can provide advice or make intelligent cost estimates. Their own attorneys can provide little help because they simply cannot interpret a law that does not exist and they are ignorant of vocational rehabilitation counseling and rehabilitation engineering.

Disabled employees are also in a great dilemma. They do not know whether the employer is obligated or is willing to provide access and to provide special tools and equipment that will permit them to be productive. They do not know the definition of "reasonable accommodations."

Few vocational rehabilitation counselors have experience in negotiating with employers to facilitate employment of severely disabled clients. Since the number of severely disabled candidates for employment will increase rapidly, it is vital that these and new counselors be trained and be provided with tools and information that will help them do their jobs.

## Approach

The RESNA publications contain many case studies where severely disabled individuals became employed when they were provided with suitable adapted tools, appropriate mobility aids and suitable worksite modifications. Authors of these cases surely have experience with many more cases and can easily obtain details of such cases.

Similarly, vocational rehabilitation counselors with severely disabled caseloads can assemble data on cases where cliente have become employed. This can be done without violating privacy since it would only be necessary to list and define disability, type of employment, cost of worksite modifications and cost of adaptive equipment. No personal or confidential information would be revealed.

These data could be collected and analyzed by regional groups. Perhaps this would be a reasonable task for existing rehabilitation engineering research centers, independent living centers or other federally funded programs. It may even be possible for state vocational rehabilitation agencies to provide much of these data. Ultimately, it would be necessary for a select group to analyze and publish the data for use by disabled clients, employees, attorneys, vocational rehabilitation counselors, engineers, courts and legislators.

Examples of case studies follow:
C.W. was a 25 year-old, speech-impaired, severe cerebral palsied

male in a manual wheelchair. He was trained in electronics theory and circuitry but could not use a soldering iron because of very poor motor control. He applied for a job as an electronic circuit board inspector and was hired in a computer fabrication plant. The company installed a limited public address system on the assembly line to accommodate the speech and mobility disabilities of the client. The cost was approximately $400 for equipment and $300 for labor. This system worked so well for the disabled client and his non-disabled co-workers that similar systems were installed on other assembly lines.

D.W. was a 30 year-old male with a severe mobility problem due to polio. He was experienced in television repair but was too short to reach the work table. The state department of human services bought a motorized wheelchair with a motorized, elevating seat for $6,000. No worksite modifications were required. This man performed as a productive electronics technician.

M.A. was a thirty-five year old woman who was quadriplegic due to polio. She interviewed for a job with a state agency where it was necessary to telephone fathers who were delinquent in child support payment. She had a good voice, but could not move her legs, arms or hands. A federal technology utilization grant paid for a special switch which was molded to her hand, a two-switch interface and a special computer, a motorized holder for papers, a recorder and a gooseneck holder for the microphone. This equipment cost about $7,500. M.A. was more productive in this job than her predecessor who was a satisfactory, non-disabled employee.

D.F. was a deaf, quadriplegic male with a high school diploma (1). He applied for a job in a fishing equipment assembly plant. He had very limited use of his hands and drove a battery powered wheelchair with two fingers. With encouragement of a rehabilitation engineers, industrial engineers at the plant fabricated a nut-driver from parts that were available in the plant. The disabled worker assembled then mechanical parts in a productive manner. Parts cost to the employer was about $100; time cost about $600, but this work was done during spare time. D.F. has worked productively for more than eight years and has required the employer to spend negligible money on special tools and facilities.

G.W. was an employed analyst with multiple sclerosis. He used a powered wheelchair and was losing the use of one hand which limited his use of the computer. A simple upper case key holddown was built for $60. This experienced and valuable employee continued to work for aeveral more years.

Implications

The above are examples of industrial cases where severely disabled individuals were hired as new employees or existing employees were enabled to continue working. Costs for accommodating these workers ranged from $60 to $7,500 and people with various, severe disabilities were involved. Cataloging and analyzing a very large number of cases would permit developing information that would correlate disability with job type and range of costs for accommodations.

Discussion

Generation of a data base relating disability to cost for worksite modification and work assist devices would be of great value to the disabled community. This would accelerate implementation and the great benefits intended by the Americans with Disabilities Act.

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Charles J. Laenger
Manager, Rehabilitation Engineering and Orthotics
Kaiser Rehabilitation Center
1125 South Trenton
Tulsa, Oklahoma 74120
(918) 584-1351 X7347

19.4

# Self Injection Aid for Persons with Cerebral Palsy

Riley Hawkins, Niki Elder, Alan Harp
Center for Rehabilitation Technology
Georgia Institute of Technology

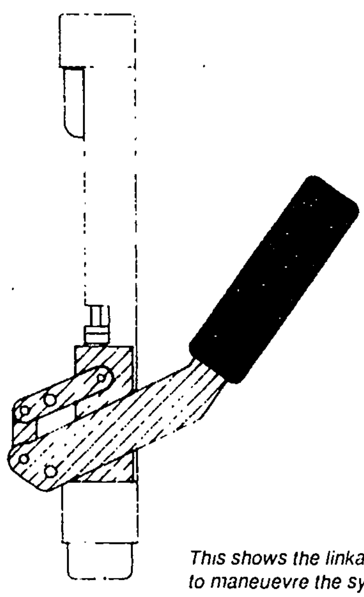
**Abstract**
A device has been developed which will allow persons with severe spasticity to administer medication through self injection. This device will help persons, who are dependent on caretakers for their injections, be able to function independently in a vocational environment. The unique design of the self injection aid eliminates the danger spasticity may cause during self injection.

**Background**
The Center for Rehabilitation Technology (CRT) specializes in developing products for person with disabilities to aid these individuals in functioning independently in a work environment. Within the past year, CRT was presented with a 21 year old woman who has cerebral palsy and is also diagnosed as a diabetic. Her spasticity caused by the cerebral palsy would cause too great a danger of injury or inadequate doses of insulin in self injection. This means the young woman must always be dependent on someone to administer her injections three times a day. She is currently living with her parents and would eventually like to live in her own home and have a career.
CRT was asked to develop a device which would allow this woman to administer her own injections, thus making her less dependent on others. The device which has been developed as a prototype is a self injection aid designed to eliminate spasticity as a danger in self injections.

**Research**
The fisrt step was to research all existing products which might help solve the problem and could be purchased on the market. What was found were several automatic insulin injectors which helped extinguish the fear and facilitate self injection, but these products did not prevent the spasticity from endangering the person while self injecting because the person was still required to hold it. What was obvious was this type of product would do all the work as long as it was held still against the arm. The product found to be the best design for the clients needs is called the JECT AID™, which would allow for the injection to be almost hands free if a way could be develop for it to be held against the skin and triggered to administer the injection.

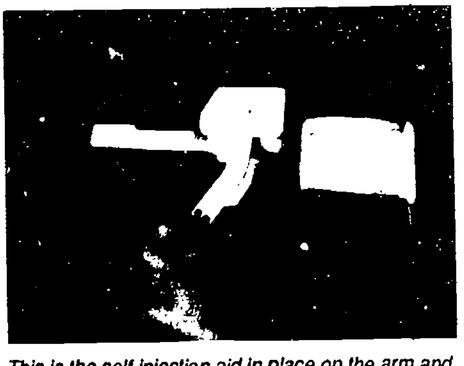
The JECT AID™ works by clasping the syringe between a spring and a trigger. Once the trigger is pushed the spring moves the syringe down inserting the needle into the skin and continues to push the plunger until the insulin is through the needle.

**Design**
The product which has been designed and developed is a self injection aid which uses the JECT AID™ as an integral part of the injection process. The self injection aid is a special cuff made to fit the legs or arms and is held on by a strap using velcro™ as the fastener. This cuff acts as a connector allowing the arm/leg and syringe to move as a unit, preventing a dangerous injection. On the outside of the cuff is a compartment where the syringe loaded JECT AID™ is snapped



*This shows the linkage used to maneuevre the syringe* in. Attached to this compartment is a handle which is part of an over center linkage. When the person moves the handle to the down position, the compartment holding the JECT AID™ moves down in to the skin, the JECT AID™ is then triggered and the insulin is injected. The handle in the down position locks the syringe in place while the needle is in the skin and the insulin is injected. This prevents any spasticity from affecting the injection.

The steps taken to use the self injection aid would be to prepare a syringe with the accurate amount of insulin and place the syringe into a JECT AID™ and store in the refrigerator. The number of injections stored would depend on the required amount of insulin needed daily by the person. This step could be done by a caretaker.The next step involves only the person who is to receive the injection. A prepared JECT AID™ is removed from the refrigerator and placed in the self injection aid. The person then slides the cuff of the self injection aid on the arm or leg to the position required for accurate injection and fastens the velcro™ straps. Then with one motion, the person pushes the handle downward. This single motion moves the JECT AID™ down into the arm or leg, sets off the spring which pushes the syringe needle into the skin and administers the insulin. After the plunger in the syringe is completely down, the person then raises the handle, unfastens the straps and removes the self injection aid.



*This is the self injection aid in place on the arm and ready to administer the medication.*

**Evaluation**

The Center for Rehabilitation Technology has developed a device which will enable a person with severe spasticity to give themselves injections for medical purposes. The self injector aid was specifically designed for a person with cerebral palsy who must receive insulin injections 3 times a day. The device was taken to her home and tested for usability by her. With the aid of a table surface, she was able to insert the prepared JECT AID™ in the self injector aid, put the cuff on her arm and fasten the straps. Because of her cerebral palsy, she does struggle with this task and it takes a little more time than depending on someone else to administer the injection, but the purpose of the device is to give people an opportunity for independence and security in knowing there is a way for self injection.

The self injection aid is currently with the clients physician who specializes in diabetes. He will test the device on the client and give his suggestions or comments regarding the reliability and utility of the product. We should have a response before June 1992. The very unique element about the self injection aid is its capability of preventing the spasticity to interfere with the administration of the medication.

**Acknowledgments**

This device was supported by the State of Georgia Division of Rehabilitation Services. Donations of special materials were made by Abbey/Foster Medical.

Riley Hawkins
Center for Rehabilita.ion Technology
Georgia Institute of Technology
Atlanta, GA 30332-0156

19.5

# CHILD SWING WITH 100 POUND CAPACITY

Riley Hawkins, Alan Harp, Cabell Heyward
Center For Rehabilitation Technology
Georgia Tech

ABSTRACT

The benefits of sensory stimulation through swinging have long been recognized in the field of rehabilitation, but access to in-home therapy has been limited to available baby swings. Motor driven and wind up baby swing manufacturers in North America have universally adopted a 25 pound load limit. Today, if a therapist wishes for continued sensory stimulation after discharge he or she must hope that the patient weighs less than 25 pounds or that the family has a maid willing to push the porch swing. The development of a swing with a 100 pound capacity is discussed here. The new swing looks to fill the voids in the current designs, most importantly providing motor driven sensory stimulation therapy to families with toddlers and young adults.

BACKGROUND

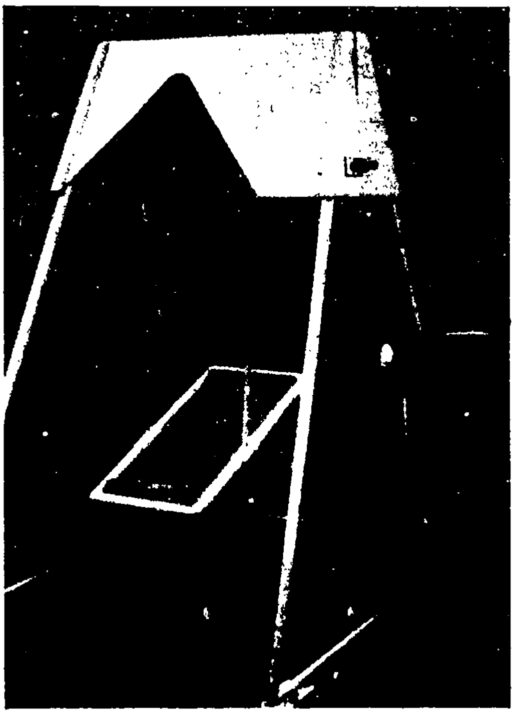
A fifteen month old baby girl entered our case load in April of 1990. The child and mother previously suffered from a condition known as velamentous insertion. During labor this resulted in a separation of the umbilical cord from the placenta prior to an emergency cesarean section. The loss of blood and prolonged oxygen deprivation is manifest in severe cognitive and physical disabilities but the child came through the emergency, is stable, and continues to improve.

During early hospitalization, physicians and the family discovered the utility of the swinging motion. It was particularly useful in the reduction of seizures. At 15 months, however, she already weighed 25 pounds and her swing was beginning to wear. Aswing was needed to continue therapy in her new hospital facility and eventually at home.

A product review turned up numerous baby swings and numerous school/therapy department swings. The baby swings, as mentioned had load limits of 25pounds- not only the frames but the swing mechanisms themselves. They also used replaceable batteries or had to be wound up constantly. The therapy equipment swings were not motor driven and were generally too large to be practical in a home environment. A swing sturdy enough to accomodate growth into young adulthood and conveniently designed for in home use was not available.

DESIGN

A tubular steel frame swing was developed for delivery in April of 1991. It is shown below standing beside a Fisher-Price baby swing™ for comparison. The frame has a footprint of 5 1/2 feet by 4 1/2 feet and stands 6 1/2 feet tall. It disassembles into four pieces for storage or can be unlocked and rolled from place to place on its locking castors. The bucket seat has a three position tilt mechanism and was designed for use with a foam-in-place insert. It is expected that this seat will need to be replaced when the child reaches 50 or 60 pounds. The support poles and seat are easily removed so that they may be interchanged with the next seat whether it is a similar design, a prefabricated bucket seat, or custom seating pans. The height of the seat itself matches that of the child's wheelchair. As the child gains in size and weight, this along with the ample head room will accomodate easy transfers.

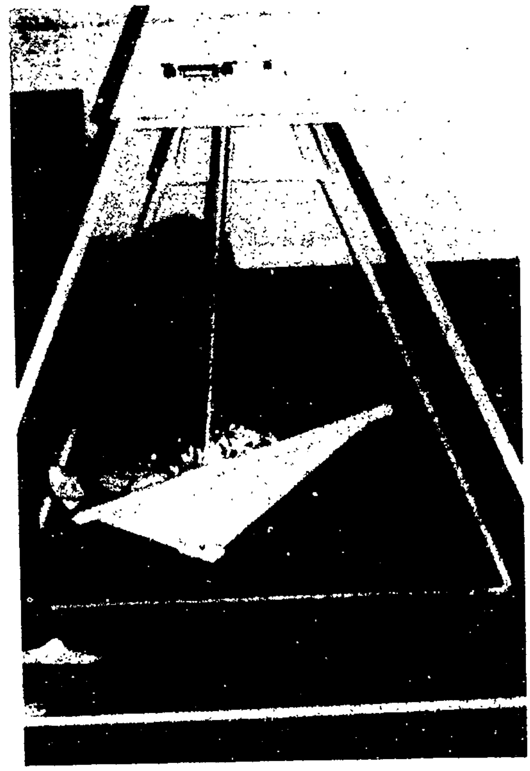


100 POUND CAPACITY SWING

The swing operates from a standard wall outlet so it never needs winding or new batteries. A single switch turns on a quiet DC motor to drive the swing mechanism. If for some reason the motion is accidentally interupted, the unit will idle until the obstacle is removed, and in a few seconds gently return to a smooth swing. During swinging the child can listen to soft (or hard) music from a stereo radio/cassette player which was included within the upper housing at the parents request.

EVALUATION

The swing was installed at a local special hospital in April of 1991. Father and daughter are seen here getting ready to swing. The swing has been operating for 10 to 14 hours a day ever since(more than 2000 hours of use). The client now weighs 40 pounds and the swing continues to operate as designed. The family noted that improvement in upper limb function has become hampered by the tubes which support the bucket seat. Alternative supports are now being discussed.



Father and Daughter

DISCUSSION

It was the goal of this project to provide a working swing for our client. It is the goal of this paper, however, to expose the shortcomings of current swing designs. The need for a continious operating swing with high load capacity and functionality in the home is evident. If you would like more information about this project or would like to encourage manufacturers to produce a similar swing please contact the author.

Riley Hawkins
Center for Rehabilitation Technology
Georgia Tech
490 Tenth St.
Atlanta, GA 30332
(404) 894-4960

19.6

# Development Of A 3-Dimensional Measurement System For Measuring Alignment Of Artificial Limbs

K.A. Moslehi, S.E. Solomonidis, J.P. Paul
Bioengineering Unit, University of Strathclyde,Glasgow.

## Introduction

Alignment of a prosthesis is defined as the position and orientation of the socket relative to the other prosthetic components of the limb. In current prosthetic practice, to record the configuration of a prosthesis, the alignment is subjectively "gauged" to an unknown accuracy. As the limb alignment configuration can not be measured with any degree of certainty, loss of alignment during various stages of limb construction or delivery can interfere with the effort of the prosthetist in achieving the optimal alignment. Hence, the need for equipment to allow the measurement of limb alignment has become evident.

## Design

Equipment for measuring the alignment of lower limb prostheses in a clinical situation has been designed. The system is based on the principles of alignment definition as developed at the University of Strathclyde. Zahedi et al. (1) The system as shown in figure 1, consists of an aluminium framework having a horizontal baseplate, a vertical column supports an upper and a lower bracket for holding the socket and the shank of a prosthesis. The column also carries two sets of linkages, an upper set which measures the position and inclination of the socket relative to the foot, and a lower set which measures the position and inclination of the knee joint relative to the foot. The axis of the socket is determined by means of a specially designed socket axis locator. The lower assembly incorporates a spring loaded caliper arrangement which locates on either side of the knee spindle. The toe out/in angle of the foot is determined by a plate which is able to swivel about the centre of the system coordinate axis on the base plate. The linkages, each having six joints offer six degrees of freedom, allowing the measurement of artificial limbs with any configuration or size.

The system connects to a personal computer via an interface. Software is designed to acquire the data, perform calculations and present the alignment data. A patient filing system is also incorporated. The operation of the software is through screen menus. The system defines a coordinate axis reference on the socket of prosthesis according to a procedure described by Lawes et al (2), locates the knee spindle and finally compares position and orientation of the socket and knee joint with the axis of prosthetic foot. The alignment data are in terms of socket height, antero/posterior and medio/lateral shift and tilt, foot toe in/out rotation and in the case of an above-knee prosthesis data includes knee height and antero/posterior medio/lateral shift and medio/lateral tilt.

The system can be operated by a semi-skilled operator and on average it takes 10 to 15 minutes to measure a below-knee or an above-knee prosthesis respectively. The expected accuracy of such system is $\pm$1mm and $\pm$0.5° degree for shift and tilt respectively.

## Calibration of the system

The system is calibrated using a specially designed mandrel resembling an above knee prosthesis with known geometrical configuration. The geometry of the mandrel is such that once it is set on the measurement rig, the main axis line of the socket section (two concentric cylinders) passes through the centre of the foot plate coordinate axis system, hence giving zero tilt and shift in all direction of measurement. Two asymmetric holes on the body of the mandrel resemble the axis of the knee, again there is no tilt or shift relative to the main frame coordinate system.

## Field trials

The field trial was carried out at two Hospitals in Glasgow and at the Bioengineering Unit;

fifty A/K and B/K legs were measured, repeatability of the system was assessed by measuring each leg five times consecutively and before every measurement , the leg was removed and repositioned in the rig, and measurements for every leg were compared.

## Discussion

During the field trials it was demonstrated that, while the present prototype requires certain improvements in the design and manufacture, such a system can deliver accurate and repeatable measurement of the alignment parameters. The operation of the measurement system is very much in-line with the usual procedure of making a leg, hence it does not require any extra effort by limb fitting staff. Quantification of alignment would allow the limb fitting staff to check the alignment at any stage of limb construction. Moreover, the measurement of the alignment parameters would provide a permanent record which would be useful when a duplicate prosthesis is required.

In using such a measurement technique, the prosthetist is able to record any changes made to the alignment of their patients.

The present prototype system requires certain improvements in the design and manufacture, the completion of the alignment measuring rig shall offer new opportunities to prosthetists to enhance their technique of aligning prostheses more effectively.

## Acknowledgments

Funding for the research was provided by The Scottish Home and Health Department - U.K..

## References

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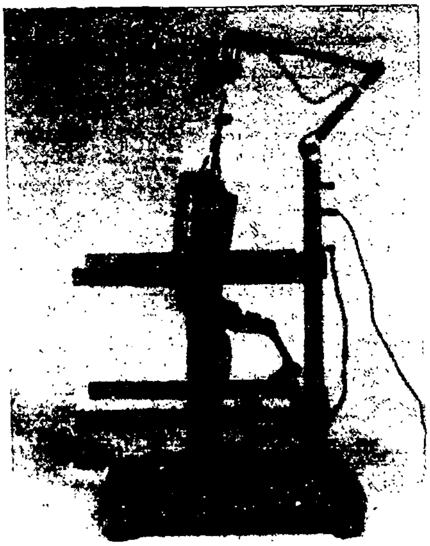
"Alignment of Lower Limb Prostheses". J. Rehab. Res. Devel. 23 (2) 2-19.
2. Lawes P., Loughran A., Berme N.: Lower limb anatomical and prosthetic frames of reference. In: Non-Invasive Clinical Measurement,(Biological Engineering Society 15th Anniversary International conference, Edinburgh, August 1975) DEM Taylor, J Whammond (eds). London: Pitman Medical 1977.

Kamran Moslehi
Bioengineering Unit
University of Strathclyde
106 Rottenrow
Glasgow G4 0NW
Scotland U.K

Figure 1 - Alignment measuring system.



# ASSESSMENT OF TRANSPORTATION TECHNOLOGY: SURVEY OF CONSUMERS

Belinda O. Morris, Stephen H. Sprigle, Patricia E. Karg
Transportation Rehabilitation Engineering Center
University of Virginia
U.S.A.

## ABSTRACT

A survey was sent to spinal cord injured individuals who travel in a personally-owned van. Fifty-two percent drove their van and 59% rode as passengers (some respondents drove and rode as a passenger). Personal funds were used by 88% of respondents to pay for their van. Adaptive equipment was paid for by the personal funds of 62%. Generally, consumers were satisfied with their adaptive equipment.

## INTRODUCTION

Special adaptive equipment needs increase in order for disabled persons to obtain a high level of independence in areas such as self care, mobility, employment, leisure, and personal transportation. Upon becoming disabled, individuals have reported not only being physically disabled but also "financially disabled". Adaptive driving equipment costs range from as little as $50 to as high as $50,000. In addition to cost, consumers also have other issues related to transportation such as repairs to existing equipment, time required for repairs, alternative transportation while their vehicle is in repair, and payment for repairs. Other concerns include assurance that the adaptive equipment prescribed is truly necessary for the safe operation of a vehicle. These issues don't even address the costs and time required for driver's training. In order to meet the needs and safety issues of the disabled consumer, their perceptions and experiences should be determined.

## OBJECTIVE

A survey of individuals using adaptive transportation equipment as passengers or drivers was conducted to identify problems associated with obtaining and using adaptive transportation equipment, and to determine the desires and needs of disabled individuals who use this equipment. The overall objective was to address safety issues of transportation using adaptive equipment.

## METHOD

The target population for the consumer survey was spinal cord injured persons in Virginia who use a privately owned van for transportation. This sample was identified using an existing database of persons with spinal cord injuries maintained by the Virginia Spinal Cord Injury System (VSCIS). To be included in the survey, a person must: 1) have been 16 years old or older, 2 ) have a functional spinal injury at T1 or above or have a central cord or Brown-Sequared syndrome, and 3) enter a personally owned van in his/her wheelchair. VSCIS sent a survey to each person who met this criteria and followed up the mailing with a telephone call.

Users were asked to report on types of equipment used, service issues, and their perceptions of satisfaction with the equipment. The survey focused on wheelchair tie-downs, occupant restraints and driving equipment.

## RESULTS

Surveys were sent to 200 spinal cord injured persons and 128 responses (64%) were received. Thirty-nine percent of the respondents were drivers only, 13% were drivers and passengers, and 48% were passengers only. Of the 65 respondents who drove, only 14 (21%) drove from their wheelchairs. Nearly all of the individuals drove prior to their injury (98%), and 64% of the respondents had been injured for over 5 years (Table 1). Most respondents used Ford (58%), GM (25%) or Chrysler (15%) vans (Table 2).

Table 1. *Number of Years Disabled*

| | |
|---|---|
| 0-2.5 years | 12% |
| 2.6-5.5 years | 24% |
| 5.6-10.5 years | 37% |
| 10+ years | 27% |

Table 2. *Type of Van*

| | |
|---|---|
| Ford | 55% |
| GM | 25% |
| Chrysler | 15% |
| VW | 2% |

Personal funds were used by 88% of the respondents to pay for the majority of their van's cost (Table 3). Over 60% of the respondents used personal funds to pay for the majority of the adaptive equipment costs. The Vocational Rehabilitation department was named by 22% as paying the majority of the equipment costs (Table 4).

Consumers listed problems with their adaptive equipment over the previous 12 months (Table 5). Access and exit equipment had the greatest incidence of problems. Forty-four percent of the respondents with lifts reported a problem as did 2 of the 6 respondents with ramps.

Consumers were asked to estimate the repair costs to their adaptive equipment over the pervious year. A majority of the repair costs (61%) were less than $100 and took 1 day or less (59%) to complete repair. Adaptive equipment repairs were most often paid for by personal funds (83%) (Table 6). Repair work was mostly done by the consumer or their family/friends (36%), followed by the equipment installer (34%) or a service station (20%) (Table 7).

Of the individuals who ride as a passenger while seated in their wheelchair, 83% utilized a tie-down and 56% used an occupant restraint. Wheelchair tie-downs were used by 86% of those who drive from their wheelchairs, and 54% of these respondents use occupant restraints.

Adaptive equipment satisfaction was determined by analyzing responses to questions concerning durability, safety, and difficulty in using equipment, and whether respondents reported problems with the equipment. Equipment satisfaction is listed in Table 8.

**Table 3.** *Who paid the majority of the van's cost?*

| | |
|---|---|
| Personal funds | 88% |
| Service club/church | 5% |
| Other | 7% |

**Table 4.** *Who paid the majority of adaptive equipment costs?*

| | |
|---|---|
| Personal funds | 62% |
| Voc Rehab Dept | 22% |
| Insurance | 9% |
| Service club/church | 4% |
| Other | 3% |

**Table 5.** *Problems in the Last 12 Months*

| Equipment | # of Respondents | % With Problems |
|---|---|---|
| Lift | 46 | 44 |
| Hand Controls | 65 | 9 |
| Ramp | 6 | 33 |
| Steering Equip | 65 | 9 |
| W/C Tie-down | 74 | 13 |
| Interior control | 65 | 15 |
| Drop pan | 4 | 25 |

**Table 6.** *Repairs Paid For*

| | |
|---|---|
| Personal funds | 84% |
| Insurance | 6% |
| Vocational Rehabilitation | 5% |
| Warranty | 4% |
| Other | 2% |

**Table 7.** *Repairs Adaptive Equipment*

| | |
|---|---|
| Self, family, friends | 36% |
| Equipment installer | 34% |
| Service station | 20% |
| Rehabilitation facility | 6% |
| Other | 5% |

**Table 8.** *Equipment Satisfaction*

| Equipment | # of Respondents | Percent Satisfied |
|---|---|---|
| hand controls | 57 | 86 |
| dr occ restr | 7 | 86 |
| steer equip | 44 | 84 |
| lift | 119 | 83 |
| pass occ restr | 45 | 80 |
| pass tiedown | 57 | 72 |
| dr tiedown | 12 | 50 |
| ramp | 6 | 50 |

## DISCUSSION

This survey was limited to spinal cord-injured individuals in the state of Virginia. Therefore, the results reflect personal transportation in this state and do not necessarily generalize to other states. Certain issues like funding and equipment are greatly influenced by agencies, driver evaluation programs, and vendors in the state. A similar survey has been administered in Arkansas, whose results will allow comparison between two states in different regions of the country.

Most of the consumers (98%) had driven prior to their injury, but yet only 52% drive following an injury. Why is it that these individuals do not return to independent driving? Is it a funding issue, a safety issue, a physical ability issue, or due to a lack of desire? One possible answer to these questions can be found in Tables 3 and 4. In the state of Virginia, personal finances are the largest funding source for both vans and adaptive equipment, and therefore, available funding probably hinders some consumers from returning to independent driving.

In Virginia, the Vocational Rehabilitation Department typically funds only adaptive equipment, but still was the primary payment source for only 22% of the respondents. We cannot determine how many of these SCI respondents qualified for VR services, but given the adult group sampled, more coverage by other services or agencies was expected. As the data indicate, personal transportation in Virginia depends heavily on personal finances.

The incidence of problems with adaptive equipment varied depending on the type of equipment (Table 5). Regardless of the problem, most of the repair costs were minor, generally costing less than $100 and taking a day or less to repair.

Because most equipment problems were minor, they seemed to have little effect on the opinion that users have of the equipment. For example, 44% of the respondents with lifts reported having a problem, yet 83% of them are satisfied with the equipment. The lowest percentage of satisfied users was for driver tie-downs and ramps. Only 50% of the respective users of this equipment were satisfied, but these two types of equipment had fewer users which might have skewed the results.

Over 80% of van passengers and drivers report utilizing wheelchair tie-downs, but only about 50% of respondents seated in wheelchairs use occupant restraints. The use of tie-downs is encouraging, but lack of occupant restraint use is clearly an issue that must be addressed. Adequate design of occupant restraints for persons seated in wheelchairs is difficult, given the different designs of wheelchairs and the functional abilities of wheelchair users. Most of the drivers and passengers who use occupant restraints seemed satisfied (Table 8), but anecdotal evidence suggests that an improved design would allow more individuals to use occupant restraints independently.

Most van drivers transfer from their wheelchairs into the original OEM captain's chairs. Individuals are encouraged to transfer to the original seat in the vehicle because it has been tested by the manufacturer to sustain forces generated while driving and in the event of a collision.

## ACKNOWLEDGEMENTS

We would like to thank those individuals who responded this survey. Special thanks to Dr. George Nowacek, Office of Medical Education, for his assistance in survey design and analysis, and Julian Hickman of VSCIS for administration of the survey. This project was made possible by funding from NIDRR, Department of Education, grant # H133E00006.

For further information, please contact:

University of Virginia
Transportation REC
P.O. Box 1885 - University Station
Charlottesville, VA, U.S.A. 22903
(804)296-4216

# ASSESSMENT OF TRANSPORTATION TECHNOLOGY: SURVEY OF DRIVER EVALUATORS

Stephen H. Sprigle, Belinda O. Morris, Patricia E. Karg
Transportation Rehabilitation Engineering Center
University of Virginia
U.S.A.

## ABSTRACT

A survey was sent to 403 driver evaluators and trainers throughout the United States, and 138 responses (35%) were received from 44 states. Most of the respondents were experienced evaluators; 62% were occupational therapists. They were asked to report on methodologies, equipment, and criteria used when accessing an individual's ability to drive. Measurement of specific driving characteristics was reported as being more important than measuring non-specific physical characteristics, yet only 50% of evaluators measure all of the defined driving characteristics. Most characteristics are measured through observation or a functional test rather than using equipment. The overwhelming majority of evaluators use subjective criteria or no criteria when analyzing the results of a test. Despite, these results, 66% of evaluators report being satisfied with their current evaluation equipment.

## INTRODUCTION

For many individuals with disabilities, the rehabilitation process includes an evaluation to determine driving potential with the use of assistive equipment. This process usually begins with a driving evaluation designed to predict the ability of a person to safely operate a motor vehicle. Driver evaluation programs across the United States are becoming more prevalent, yet, at this time, are generally unregulated and have no nationwide policy of quality assurance. The methodologies used in driver evaluation and training programs are not standardized, relying on several factors, including the education and training background of the evaluator, and available evaluation and training equipment. Recently, a need and desire to improve the quality and consistency of driver evaluations has been expressed by professionals in the field (1). In order to affect change in evaluation procedures, the current practices and methodologies used across the country must be determined.

## OBJECTIVE

A survey of driving evaluators and instructors was conducted to determine the methodologies, equipment, and criteria utilized in determining the driving potential for individuals with disabilities. The overall objective was to collect information that could be used to guide research efforts in developing improved methods and/or equipment used in the evaluation of disabled drivers.

## METHODS

The target population for the evaluator survey was every driver evaluator and trainer in the United States. A list of potential respondents was compiled from information disseminated by several groups, including ADED, AOTA, RESNA, AAA, and the GM Mobility Program. Each person was sent a survey and a follow-up postcard and/or a telephone call if no response was received.

Evaluators were asked to report on the physical and driving characteristics measured during an evaluation and the methods used to determine these characteristics. The survey also included questions concerning equipment use in training vehicles, prescribed equipment, standards, and funding, but these results will not be reported due to space limitations. Cognitive and visual tests, while important in driving, were determined to be beyond the scope of this survey and were not included.

Physical characteristics were defined as non-specific functional abilities which included, *range of motion (ROM), manual muscle strength, sensation, grip strength, pinch strength, fine motor dexterity*, and *eye-hand coordination*. Driving characteristics were defined as functional abilities specific to driving which included *gas force, brake force, steering force, brake reaction time*. and *steering reaction time*.

## RESULTS

The survey was sent to 403 evaluators and trainers, and 138 responses (35%) were received from 44 states. Most respondents (60%) had been performing driver evaluations for more than 5 years. Most of the respondents were occupational therapists (62%), with corrective therapists (17%) and evaluators with an education degree (18%) accounting for the most of the rest. Evaluators generally worked at a medical facility (80%), rather than a educational facility (5%) or a dedicated driving program (6%). The driving programs where the respondents worked varied in size, but 87% had at least on car and 43% had at least one van. Incidently, most cars were from GM (76%)

and were less than 5 years old, and most vans were from Ford (87%) and were more than 5 years old.

The perceived importance of each driving and physical characteristic is listed in Table 1. As stated previously, evaluators were asked to rank each between 1 (*not important*) and 5 (*essential*). The percentage of respondents who measured each characteristic is also listed. Driving characteristics were perceived as more important than the physical characteristics, yet a lower percentage of evaluators measure driving characteristics. Generally, respondents who measure a characteristic ranked it as more important than those who did not measure that characteristic. Respondents were grouped according to their background as therapy, education, and other. Only the perceived importance of *brake force* and *manual muscle strength* differed significantly according to the evaluators' backgrounds.

The methods used to measure driving and physical characteristics varied greatly. Many were determined through observation or via functional tests; evaluation procedures exhibited little consistency across respondents. The most common measurement technique reported by respondents who measured each physical characteristic involved equipment or a standard evaluation procedure (Table 2). Driving characteristics were most commonly determined by observing the task while in an evaluation vehicle, except *brake reaction time* which was most often measured using commercially-available equipment (Table 3).

**TABLE 1.** *Perceived Importance*

| Characteristics | Avg Score | % of Respondents |
|---|---|---|
| br react time | 4.55* | 89.9 |
| st react time | 4.51* | 56.5 |
| brake force | 3.66*+ | 50.7 |
| steering force | 3.51* | 57.2 |
| gas force | 3.44* | 51.4 |
| ROM | 3.27 | 95.7 |
| sensation | 3.23* | 78.3 |
| man musc strength | 3.17*+ | 94.9 |
| eye-hand coord | 2.90* | 78.3 |
| fine motor coord | 2.79 | 65.9 |
| grip strength | 2.68* | 87.7 |
| pinch strength | 1.61* | 64.5 |

* scores of measure vs. do not measure groups were significantly different at $p < .05$
+ scores differed significantly by background of respondent ($p < .05$)

The respondents reported on the criteria or norms used to judge an individual's driving characteristics. Most respondents used subjective criteria or no criteria when analyzing the results of their evaluation. The prevalence of criteria is included in Table 4, as is the percentage of respondents who used equipment to measure the particular characteristic rather than an observational or functional test.

When asked if their evaluation equipment was adequate, 66% of the respondents answered 'yes'.

**TABLE 2.** *Physical Characteristic: Most Common Measurement Method*

| Characteristic | Most Common Method (% Respondents) |
|---|---|
| ROM | goniometer (55%) |
| man musc strgth | man musc test (55%) |
| sensation | position sense (60%) |
| grip strength | dynamometer (62%) |
| pinch strength | pinch meter (54%) |
| fine motor dext | functional test (27%) |
| eye-hand coord | observation (27%) |

**TABLE 3.** *Driver Characteristics: Most Common Measurement Method*

| Characteristic | Most Common Method (% Respondents) |
|---|---|
| gas force | in vehicle (17%) |
| brake force | in vehicle (20%) |
| steer. force | in vehicle (58%) |
| br react time | Porto-clinic (44%) |
| st react time | in vehicle (55%) |

## DISCUSSION

Results of this survey are useful in defining current evaluation procedures and equipment. Analysis of these results illustrates the lack of a standard methodology in determining driving capability, and may identify some areas where further research and development are needed.

All the physical characteristics were rated lower in importance than the driving characteristics, yet a higher percentage of respondents measure physical characteristics. This may occur because physical characteristics can be measured with simple inexpensive equipment or by techniques commonly used by therapists.

Respondents who measured a particular characteristic tended to rate its importance higher than respondents who did not measure that characteristic. This result seems to demonstrate the lack of standardized evaluation procedures, and even the lack of a consensus on the importance of particular measurements.

Analysis of the responses after dividing the evaluators into three groups according to their educational background (therapy, education, and other) did not produce many significant results. Only *brake force* and *manual muscle strength* was judged differently across the groups. This result can be interpreted in several ways including: the lack of evaluation standardization crosses all educational backgrounds, and the perceived importance of each measure is due to something other than an evaluator's education.

Surprisingly, 66% of the respondents were satisfied with their evaluation equipment, yet only about 50% of them measure all of the driving characteristics they reported as important. One possible explanation for this may be that evaluators feel that the ability to drive is better determined in a vehicle rather than by a clinical test. However, the lack of inexpensive clinical equipment that can mimic necessary driving functions may deprive potential drivers judged as 'unable to drive', of the opportunity to practice, train, and improve before entering a training program.

Another area that seems lacking is the availability and use of established criteria to judge the driving characteristic measures. Except for *brake reaction time*, an overwhelming majority of evaluators who measure driving characteristics, use subjective or no criteria after performing the test. Research in this area may be warranted to identify equipment able to measure these characteristics and then determine a relationship between test results and actual driving ability.

## REFERENCES

1. Brubaker, Digges, Sprigle, Thacker, eds, **Transportation I**: *A State of the Art Conference on Personal Transportation for Persons with Disabilities*, RESNA Press, 1991.

## ACKNOWLEDGEMENTS

We would like to thank all of the individuals who responded to this survey. Special thanks to Dr. George Nowacek, Office of Medical Education, for his assistance in survey design and analysis. This project was made possible by funding from NIDRR, Dept. of Education, grant H133E00006.

For further information, please contact:

University of Virginia
Transportation REC
PO Box 1885 - University Station
Charlottesville, VA, U.S.A. 22903
(804)296-4216

TABLE 4. *Criteria Used with Driving Characteristics*

| Measure | % who use equipment | commercial company criteria | in-house criteria | subjective or no criteria |
|---|---|---|---|---|
| gas force | 31% | 6% | 12% | 82% |
| brake force | 33% | 6% | 17% | 77% |
| steering force | 44% | 4% | 16% | 80% |
| br react time | 85% | 73% | 6% | 21% |
| st react time | 45% | 26% | 12% | 62% |

20.3

# ASSESSMENT OF TRANSPORTATION TECHNOLOGY: SURVEY OF EQUIPMENT VENDORS

**Stephen H. Sprigle, Belinda O. Morris, Patricia E. Karg**
**Transportation Rehabilitation Engineering Center**
**University of Virginia**
**U.S.A.**

## ABSTRACT

A survey was sent to 370 equipment vendors and vehicle modification companies throughout the United States, and 123 (34%) responses were received from 36 states. Most vendors seemed satisfied with the equipment prescriptions that they received from evaluators. A majority of the respondents custom fabricated or modified driving and safety equipment. Lifts and external controls were reported to be the least difficult to install, yet were the most common equipment serviced by the respondents. This information will be used to study adaptive driving equipment and to develop equipment evaluations and vehicle modification procedures.

## INTRODUCTION

In order to drive safely, an individual with a disability often requires adaptive driving equipment. Equipment vendors and vehicle modifiers become involved in the process of appropriate equipment acquisition and play an important role in ensuring consumer safety. The knowledge and experience of these vendors, as well as the methods used to modify vehicles are important to the study of personal transportation. A few states regulate vehicle modifications and equipment installation through inspection, but generally, this aspect of assistive technology remains unregulated. The National Mobility Equipment Dealers Association (NMEDA) has recognized the need for certification of vendors and has been developing a certification process for its members. The Society of Automobile Engineers (SAE) is addressing the issue of quality assurance by developing recommended practices on vehicle modifications, hand controls, powered controls, lifts, and tie downs and occupant restraints. These endeavors are being developed to increase the safety of personal transportation for persons with disabilities.

## OBJECTIVE

A survey of adaptive driving equipment vendors was conducted to collect information on equipment, installation, servicing, and funding issues. The overall objective was to identify modification and equipment practices and equipment issues that would be useful in the development of standards and the design of optimal equipment and systems.

## METHODS

The target population was every vendor in the United States. A list of potential respondents was compiled from information disseminated by several groups including NMEDA, ADED, AAA, RESNA, SAE, and the GM Mobility Program. Each person was sent a survey and a follow-up postcard and/or telephone call if no response was received.

Vendors were asked to report on the types of equipment they install and service, structural modifications performed, equipment prescriptions, and funding sources that pay for their services. The survey focused on many types of equipment, including raised roofs, lifts, dropped floors, drop pans, six-way power seats, hand controls, power controls, occupant restraints, and tie downs.

## RESULTS

Surveys were sent to 370 vendors, and 123 responses (34%) were received from 36 states. Two-thirds of the respondents were members of at least one national organization (Table 1). The majority of respondents were full-service vendors who performed all of the work necessary for a van modification, rather than contracting out the work, or referring the customer elsewhere (Table 2). Twenty-five percent of the vendors reported doing driver evaluations themselves.

Table 1. *Membership in National Organizations*

| Organization | % of respondents |
|---|---|
| NMEDA | 52 |
| ADED | 25 |
| RESNA | 10 |
| Not a member of an organization | 34 |

Table 2. *Type of Work Done*

| Type | Percent of respondents |
|---|---|
| lift installation | 96 |
| electric wiring | 95 |
| 1 & 2 controls | 90 |
| welding | 86 |
| raised roof | 82 |
| drop floor | 80 |
| conversion van | 65 |
| zero/reduced effort controls | 60 |

About one half of the vendors felt appropriate equipment was prescribed for their customers (Table 3), and only 5% reported changing prescriptions regularly (Table 4).

Vendors were asked to estimate how often they fabricated equipment or modified commercially-available equipment for their customers (Tables 5 and 6). Console and secondary controls were the most commonly fabricated or modified by the respondents.

Installation of lifts, raised roofs, and external lift controls were the least difficult installations according to the respondents (Table 7). Lifts, external controls and six way power seats were identified as the equipment requiring most frequent service (Table 8).

Vendors reported on the funding sources that purchased vehicles and equipment for their consumers (Table 9). The Veterans Administration (VA) was named by 90% of the respondents as a purchaser of both vans and equipment. State agencies purchase equipment (90%) more often than vehicles (45%). Insurance and Workman's Compensation programs were also named as common sources of funding. Blue Cross/Blue Shield and Medicare/Medicaid were rarely named as funding agencies, being mentioned by about 10% of the respondents. Over 50% of the respondents acknowledged that the funding source influenced their price estimates.

**Table 3.** *Is the equipment prescribed appropriate to the customer?*

| | |
|---|---|
| Always | 48% |
| Sometimes | 52% |
| never | 0% |

**Table 4.** *How often do you change prescriptions?*

| % of the time | % of respondents |
|---|---|
| 0-25% | 62% |
| 26-50% | 33% |
| 51-100% | 5% |

**Table 5.** *Custom Fabrication Equipment*

| | % of the time | | |
|---|---|---|---|
| Custom Made Equip | 1-50% | 51-100% | never |
| lap belts | 34 | 10 | 56 |
| shoulder belts | 36 | 14 | 51 |
| console controls | 46 | 30 | 24 |
| 2° controls | 46 | 28 | 25 |
| steering devices | 33 | 7 | 60 |
| door controls | 32 | 18 | 50 |
| lift controls | 36 | 14 | 50 |

## DISCUSSION

The results of this survey provide a useful insight into the current business of vehicle modifications. Given that this is a growing industry largely unregulated, analysis of the results gives rise to interesting conclusions.

Despite being in existence only 2 years, NMEDA seems to be attracting a large percentage of vendors. About half of the respondents were members of this organization, but, of course, there is no way of determining the memberships of the 247 vendors who did not respond to the survey.

**Table 6.** *Modification of Commercial Equipment*

| | % of the time | | |
|---|---|---|---|
| Mod. to Equip | 1-50% | 51-100% | never |
| lap belts | 51 | 6 | 43 |
| shoulder belts 51 | 12 | 37 | |
| console controls | 56 | 18 | 25 |
| 2 controls | 61 | 13 | 25 |
| steering devices | 46 | 5 | 48 |
| door controls | 49 | 10 | 40 |
| lift controls | 54 | 9 | 35 |

**Table 7.** *Difficult Installation (least difficult)*

| Equipment | Often | Sometimes | Never |
|---|---|---|---|
| lifts | 0 | 23 | 77 |
| raised roofs | 1 | 18 | 81 |
| ext controls | 2 | 22 | 76 |

**Table 8.** *Equipment Serviced the Most (top 3)*

| Equipment | Often | Sometimes | Never |
|---|---|---|---|
| lifts | 26 | 71 | 3 |
| ext controls | 12 | 80 | 8 |
| 6-way seats | 8 | 83 | 9 |

**Table 9.** *Funding Vehicle and Equipment Purchase*

| | % of respondents | |
|---|---|---|
| Funding Source | Vehicles | Equipment |
| VA | 91 | 90 |
| State agency | 45 | 93 |
| Insurance | 45 | 61 |
| Workman's Comp | 38 | 76 |
| Blue Cross/BS | 5 | 8 |
| Medicare/Medicaid | 3 | 11 |

**Table 10.** *Does funding source influence price estimates*

| % of respondents | | |
|---|---|---|
| Always | Sometimes | Never |
| 11% | 44% | 45% |

Vendors seem to be equipped to handle the most common van modifications. Over 80% of them reported that their companies can install lifts, rewire the controls, raise roofs and drop floors. Installation of the highly advanced zero/reduced effort power controls was not attempted by as many vendors, as only 60% of the respondents reported performing this installation.

Vendors seem generally pleased with the equipment prescriptions that they are given by driver evaluators. They reported that the equipment prescribed was *always* or *sometimes* appropriate for the customer and only 5% reported changing the prescription over 50% of the time.

The varied functional abilities of the consumer is reflected by the amount of custom fabrication and modification of equipment done by vendors. About one-half of the respondents still find the need to custom make occupant restraints and about 60% of them report making modifications to this equipment.

The apparent frequency of customizing and modifying occupant restraints seems to identify a need for better design or at least, design criteria for this important safety equipment. Vendors are put in a difficult situation since the original equipment manufacturers' (OEM) restraint systems are not designed for use by someone driving from a wheelchair. Nonetheless, occupant restraints must be built to withstand high loads and must fit properly around the body to be effective, and custom fabrication or modification of these systems may compromise their usefulness in crash situations.

Lifts, external controls, and raised roofs were reported to be the least difficult to install, yet lifts and external controls were named as the equipment that required the most service. Frequent servicing of these two devices, in addition to six-way power seats, may signal a need for a maintenance schedule to avoid problems or possibly, the design of this equipment should be reevaluated in terms of durability.

Funding has historically been and continues to be an important issue to everyone involved in rehabilitation. The costs associated with purchasing, modifying, and equipping a van for a driver with a disability can be quite high, often exceeding $20,000. This survey collected information from the people who often must deal with an equipment prescription from an evaluator, a funding agency, and of course, the consumer.

The vendors were asked to list agencies that provide funding for vehicles and equipment. The VA seems to be the most consistent source of funding for the respondents, as over 90% of them reported the VA as funding both vehicles and equipment. Of course, the VA only covers a small portion of citizens, so consumers often must receive support from other organizations. State agencies were also named by 90% of the respondents as purchasing equipment, but a lower percentage (61%) reported that states paid for vehicles. Insurance, both private and state-supplied, and Workman's Compensation programs also fund a fair amount of transportation equipment. Insurance was named by 45% of the respondents as funding vehicles, and by 61% as purchasing adaptive equipment. Similarly, 38% of the vendors listed Workman's Comp as a purchaser of vehicles, and a slightly higher percentage (76%) mentioned it as a source for adaptive equipment funding. Blue Cross/Blue Shield and Medicare/Medicaid were mentioned by 10% or less of the respondents as funding sources. These percentages in no way reflect the portion of consumers that are funded by each agency; they simply reflect the percentage of respondents which named these agencies as funding vehicles and/or adaptive equipment.

Over 50% of the respondents acknowledged that the funding source *always* or *sometimes* influences their price estimates. A bidding process, often employed by funding agencies, is used to minimize the costs of equipment and vehicle modifications. Research is needed to determine whether the quality of the equipment or modification is compromised when a vendor consciously alters a bid according to the source of funding, and whether the bidding process rewards vendors who cut costs by cutting quality. Hopefully, the development of equipment and modifications will better ensure the quality and safety of modified vans.

In conclusion, this survey provides an interesting examination of the practices and opinions of equipment vendors. The results should prove useful for those studying the field of personal transportation, and may be applied when evaluating equipment and developing industry-wide standards.

## ACKNOWLEDGEMENTS

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For further information, please contact.

University of Virginia
Transportation REC
P.O. Box 1885 - University Station
Charlottesville, VA, USA 22903
804/296-4216

# PERFORMANCE TESTING OF WHEELCHAIR LIFTS FOR PERSONAL LICENSED VEHICLES

J.G. Thacker, Ph.D. and F. L. Cardoso, B.S.
University of Virginia Rehabilitation Engineering Center
Charlottesville, Virginia USA

## Introduction

The University of Virginia Rehabilitation Engineering Center for Personal Licensed Transportation for Disabled Persons was established to provide improved technology with potential to provide benefit to more than 250,000 Americans who would be best served with vans for their personal transportation needs. To this end a list of absolute priorities was published in the April 25, 1989 issue of the *Federal Register*. The first priority was to evaluate and test existing vehicle modification devices and equipment. These tests and evaluations will be consistent with any standards and/or specifications of existing DOT and SAE Standards for adaptive devices. The SAE has for the past several years established committees to set standards on these vehicle modification devices and equipment for the physically challenged. The SAE Adaptive Devices Subcommittee has developed a new standard for the performance of wheelchair lifts that are used with personally licensed vans. This SAE Subcommittee requested help from the University of Virginia to aid the committee's efforts in the evaluation phase of the standard. University of Virginia Transportation Rehabilitation Engineering Center agreed to evaluate the SAE Recommended Test Procedure and Recommended Practice draft documents entitled *Wheelchair Lifting Device for Entry and Exit from a Personally Licensed Vehicle, October 6, 1990.*

This proposed test procedure is for Qualification Testing of electrically powered hydraulic or mechanically operated devices which permit a person in a manual or powered wheelchair to enter or exit a personally licensed vehicle. The test procedure establishes minimum test requirements for compliance. A lift completing the test series without failure under this procedure is considered in compliance.

The test procedure consists of four series of tests which include receiving inspection tests, visual inspection of the installed lift tests, specification tests and a series of stress tests.

## Methods

Initial dimensional measurements (Table 1) were made of several different vans at local dealerships in the area (Ford, GM and Dodge) to set the basic dimensional specifications for the test device. The clearance dimensions for the table are: width 54", height 60", height from ground 42". The testing table was designed to sustain a load of 3,000 $lb_f$ at a distance approximately 21 inches from the front edge. The table is made up of three parts: the base, the legs and reinforcement angles, and the table top, (Figures 1 and 2). The base consists of a steel sheet, 5 ft. by 6 ft. by 1/4 in. The legs are made of steel angle and are bolted to supports welded to the base. The table top is 0.24 in. aluminum and is bolted to the deck supports which are connected to the legs. The test structure is equipped with a horizontal steel beam located 54 inches above the front edge of the platform to provide an anchor point for the top of the lifts.

No attempt was made in the design to simulate the dimensional constraints of a typical van door assembly other than the height. The platform is also rigid and does not simulate the elastic deformation of a typical vehicle's sheet metal structure mounted on a soft suspension system.

A loading mechanism was designed that will allow a rigid horizontal beam to be placed above the raised (van floor height) lift platform and be positioned so that a hydraulic ram can provide the 2,400 lb downward static load on the center of the platform for the Static Ultimate Load Test, (figure 3). Ricon Inc. was generous enough to donate a footplate and the hydraulic ram that conformed to the Recommended Test Procedure 5.3. The pressure in the ram is monitored by a pressure gage. The force is calculated by multiplying the pressure by the area of the hydraulic piston. The Static Proof Load Test and Accelerated Life Cycle Test loads are developed by dead weights loaded onto the lift platform.

The controls and instrumentation are shown in Figure 4. A 12 volt 125 ampere D.C. power supply provides the power to drive the lifts. The power supply is connected to 240 volt AC two phase power. A 200 amp 50 mv shunt placed in series with the +12 VDC power supply output is connected to a strip chart recorder which will record the time history current demands of the main lift motor.

Four SPDT electrical mechanical relays on the computer relay board are connected in parallel to the fold, unfold, up and down momentary switches on the pendants supplied with the lifts. If pendants were not supplied then the relays were wired to the switches directly on the lift. No other changes in the electrical circuits are made to the lift controls.

Sensing of the lift position was usually accomplished by monitoring the voltage on the two control wires to the two main motor relays. When the control logic of the lift did not automatically de-energize the main motor relays, limit switches were temporarily installed at selected positions on the lift to provide appropriate logic signals to the computer data acquisition board.

Software programs have been written in BASIC to sequence the typical lift through the unfold-down-up-fold cycle for the accelerated life cycle test by activating the correct relay after the appropriate control signals have been received.

The duty cycle for the lifts was not specified by the manufacturers; however, a maximum motor housing temperature was specified by some. A thermocouple was mounted on the electric motor to monitor the motor housing temperature. The software monitored this signal and placed the lift in a controlled wait state to allow the motor to cool down if the motor temperature exceeded the manufacturers' specification. The recommended six duty cycle delay time was monitored and if the motor did not cool down below the manufacture specified temperature rating the lift cycle testing was stopped.

Five lifts have been identified by the SAE committee and UVA TREC to be used in the evaluation, four platform lifts and one rotary lift which represent a significant spectrum of the types of lift designs. The platform lifts include track and parallelogram lifting frames driven by both hydraulic/electric and electromechanical devices. Four of the lifts were donated and one was purchased.

The evaluation consists of a number of receiving inspection tests, visual inspection of installed lift tests, specification tests and a series of stress tests. The receiving inspection tests include checking for documentation, placard placement and flammability documentation based on FMVSS no. 302. The visual inspection of the installed lift includes inspection of electrical components, chain drive components, hydraulic components, power screw components, fasteners, and controls. Also included are preliminary weldment inspections, occupant hazard test and a slip resistance test. In addition dimensional measurements, inspection for single point failure points, electrical hazards, circuit breaker, load distribution, vandal protection, wire rope tests and maintainability inspections are required. The specification tests include: control switch tests, water spray tests, electrical current tests, platform angle tests, finish coating tests, maximum acceleration tests, maximum slope tests, platform openings, wheelchair retaining tests and a threshold warning test. Tests for the manual backup system are also included.

The stress tests include an accelerated life cycle test, a static proof load test and a static ultimate load test administered in the order listed. The accelerated life cycle test consists of 4,400 loaded and unloaded cycles with the load being 600 pounds. The static proof load test consists of loading the lift to 1.5 times the rated load and then cycling 10 times with a 600 pound load. The static ultimate load test consists of a 2,400 pound load applied for two minutes.

Discussion

This proposed standard is very stringent and will require most of the manufacturers to redesign some of the mechanical components of their lifts. Most will need to add a threshold warning system (audible) which warns a user inside the vehicle that the lift is deployed as they approach the door to prevent accidental rolling of the wheelchair out of the door onto the ground. Some will need to add an automatically operating device at the ground-to-platform entry/exit area, the purpose of which is to prevent the wheelchair and occupant from rolling off the lift.

While most lifts manufactured today will not pass all aspects of the standard, most conform to a significant number of the specifications. It is expected that the standard will increase the performance and safety levels of all lifts manufactured in the future.

Acknowledgements

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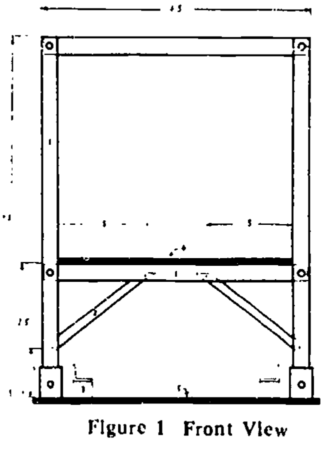

Figure 1 Front View

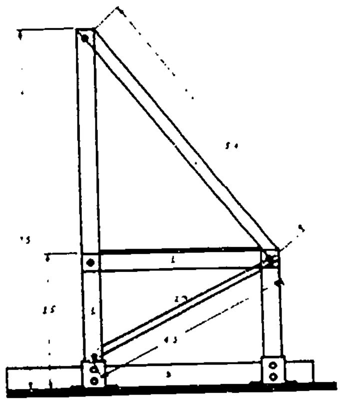

Figure 2 Side View

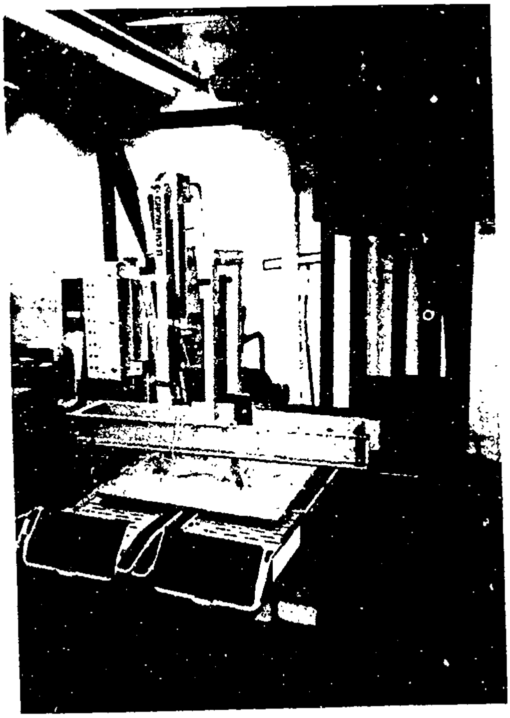

Figure 3 Ultimate Load Static Test Fixture

TABLE 1
VAN DIMENSIONS

| | FORD Club Wagon XLT | DODGE Caravan | CHEVY Van 20 |
|---|---|---|---|
| BACK ACCESS | | | |
| Width (in) | 54 | 52 | 52 |
| Height (in) | 47 | 39 | 46 |
| Height from Ground (in) | 30 | 25 | 28 |
| SIDE ACCESS | | | |
| Width (in) | 40 | 31 | 45 |
| Height (in) | 47 | 43 | 46 |
| Height from Ground (in) | 28 | 19 | 24 |

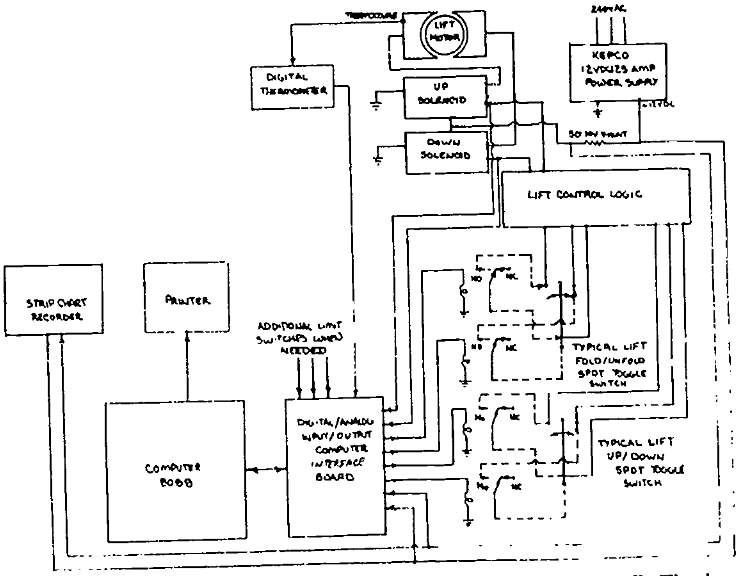


Figure 4 Controls and Instrumentation

John G. Thacker
Uva Rehabilitation Engineering Center
P.O. Box 3368
University Station
Charlottesville, VA 22903

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# KINEMATICS OF THE WHEELCHAIR SEATED BODY IN CRASH SIMULATION

Thomas Adams, Brian Sauer, Steven I. Reger
Department of Biomedical Engineering & Applied Therapeutics
The Cleveland Clinic, Cleveland, Ohio, USA

## INTRODUCTION

The use of the public transportation systems by the nearly 1.2 million wheelchair users is restricted by the lack of an easily applied universal wheelchair and user securement system. As part of the project ACTION program, funded by the Urban Mass Transportation Administration, experiments have been carried out to develop safe, user-friendly and acceptable securement systems for wheelchair users on vehicles of public transportation. This paper will describe the kinematics of a seated body in a wheelchair during crash simulation tests. The results were obtained by a rapid method of body motion analysis using high speed cinematography taken during crash simulation tests using various restraints on wheelchairs and a seated, instrumented anthropomorphic dummy. The objective of the analysis was to quantitate body movements and relate displacements during phases of the crash event to the measured kinematics of the simulation tests.

## METHODS

Proper use of lap and shoulder belts is critical to protecting travelers in automobile seats during a crash. A similar level of crash protection is needed for wheelchair passengers in vehicles of public transportation. There are fundamental differences between the mechanics of securing passengers seated in wheelchairs and automobile seats. A wheelchair is a flexible, mobile seat that is significantly higher than the automobile seat. These and other characteristics need to be considered in the design of restraints and crash simulation experiments.

A Hyge Impact Simulator (1) was used to evaluate both commercially available wheelchair tie-down systems and new concepts developed in the project. The results of these crash simulations were used to characterize the response of the test dummy. The independent variables were the wheelchair type, wheelchair restraints, use of shoulder belts, lap belt anchor points, and the magnitude of the impact.

Five views of high-speed (1000 frames/sec) films were taken to record displacements during the crash event. Data was also collected from on-board instrumentation to measure wheelchair and dummy (Hybrid III 50th percentile male) response as listed below in Table I.

TABLE I

INSTRUMENTED DATA COLLECTION DURING CRASH SIMULATIONS

**Motion**

Wheelchair acceleration (3 axes)
Dummy head acceleration (3 axes)
Dummy chest acceleration (3 axes)
Dummy hip acceleration (3 axes)
Dummy chest compression
Shoulder belt "pay-out"
Shoulder belt elongation
Lap belt elongation

**Forces**

Wheelchair to floor contact forces (3 axes)
Wheelchair restraint tension
Shoulder belt tension
Lap belt tension

## RESULTS

There was a consistent sequence of events that characterized the response of a wheelchair seated body during a simulated crash. (See Figure 1) The sequence could be applied to describe the dummy's response when seated in manual wheelchairs, powered wheelchairs and three wheeled scooters during 10 g and 20 g crashes. In all tests, the simulated impact was a half period sine wave acceleration with a duration of 100 msec. The dummy was tightly restrained by a lap belt and the wheelchair was secured to the acceleration platform. Representative data collected from the motion pictures and instruments on the

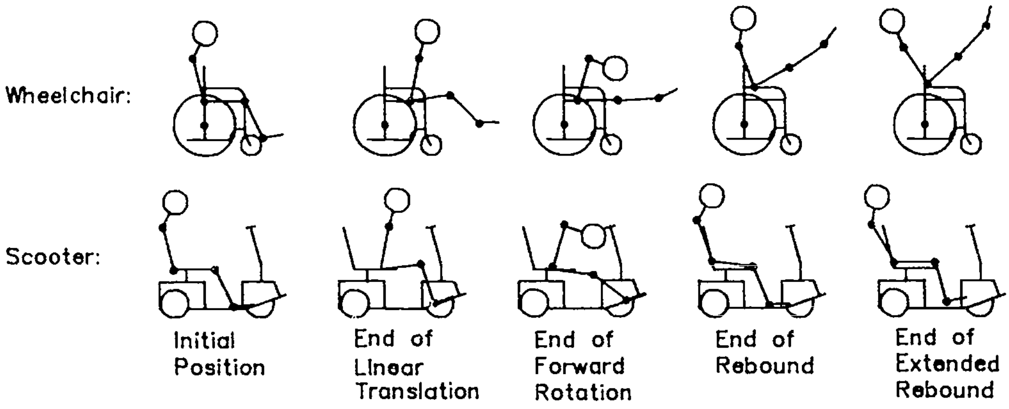


Figure 1. Kinematics of a seated body in a restrained wheelchair during a simulated vehicle crash. Lap and shoulder belts are applied

dummy and acceleration platform are shown in Table II for two wheelchair types.

### Phases of Body Movement During Crash Simulation

The body motion was divided into four phases, the end of each was defined by the movements of the hip, neck, back and head.

#### Phase I - Linear Translation

During the first 80 to 100 msec after impact, the dummy moves forward 8 to 11 inches with joint angles remaining relatively constant. This phase is highly consistent in all tests. The end of this phase is defined by the maximum forward hip motion (see Figure 2).

#### Phase II - Forward Rotation

As the hip motion reverses, the trunk, head, thighs and shins rotate forward. This is when the maximum forward displacement of the head, chest and legs occur. An effective shoulder belt significantly limits forward chest motion (see Figure 3) and reduces the duration of this phase. An inclined foot support, such as that used on three

TABLE II

PEAK DATA VALUES CHARACTERIZING DUMMY KINEMATICS

| | Scooter | | Power Chair |
|---|---|---|---|
| | Shoulder Belt 20 g | No Shoulder Belt 10 g | Shoulder Belt 20 g |
| Hip Motion (in.) | 11.2 | 11.4 | 8.7 |
| Chest Motion (in.) | 18.3 | 25.6 | 19.3 |
| Head Motion (in.) | 23.5 | 26.5 | 21.7 |
| Hip Flexion (deg.) | 108 | 135 | 115 |
| Neck Flexion (deg.) | 91 | 66 | 101 |
| Hip Acceleration (g's) | 45 | 19 | 51 |
| Head Acceleration (g's) | 66 | 35 | 83 |
| Ankle Height | 5.0 | 9.7 | 42.2 |
| Head Injury Criteria | 837 | 57 | 1311 |
| Chest Clip | 37 | 24 | 36 |
| Duration of Phase I (msec) | 100 | 110 | 80 |
| Duration of Phase II (msec) | 20 | 100 | 50 |
| Duration of Phase III (msec) | 120 | 230 | 130 |
| Duration of Phase IV (msec) | 140 | 190 | 50 |

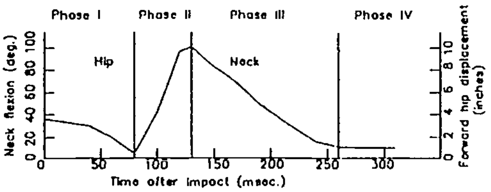


**Figure 2.** Body segment displacements in four phases of crash simulations

wheeled scooters, resists rotation of the legs and prevents excessive leg rise. Peak head and chest accelerations, major contributors to serious injury, occur during this phase. Phase II ends with maximum neck flexion (see Figure 2) and lasts 80 to 120 msec without a shoulder belt and 20 to 50 msec with a shoulder belt.

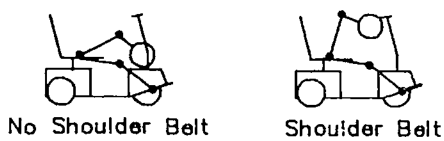


**Figure 3.** Effect of a shoulder belt in limiting forward chest motion

**Phase III - Rebound**
In this phase, the dummy rebounds toward the initial seated position. The movements are much slower during this phase, and accelerations are not significant. Movement continues until the dummy's back contacts the wheelchair seat back. The duration of this phase is inversely related to the magnitude of the crash, lasting about half as long in a 20 g crash as in a 10 g crash (see Figure 4).

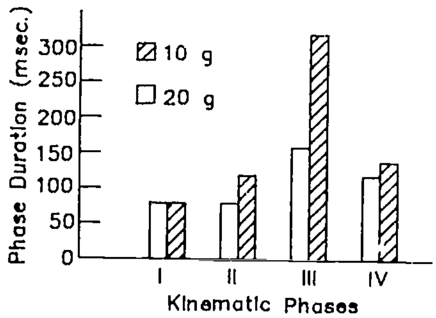


**Figure 4.** Phase duration in crash simulations witho"' shoulder belts.

**Phase IV - Extended Rebound**
The rotational inertia of the dummy continues the motion beyond contact with the seat. In some instances, the neck overextends in a whip-lash motion. The phase ends when the head reaches its maximum rearward position. This phase is significantly longer when the dummy is seated in a scooter.

Additional motion may occur beyond the end of Phase IV, but is was thought to be less significant and was not investigated.

## CONCLUSIONS

The kinematics of the response of a seated body in a wheelchair during a simulated crash have been characterized in four phases. The body motion characteristics in each phase were generally independent of wheelchair type, wheelchair restraint characteristics and the magnitude of impact force. The duration of the phases has been shown to be affected by use of a shoulder belt, wheelchair type and impact magnitude.

The relationship between the phase duration and the risk of injury to the wheelchair user is being investigated. The dummy's motion described here should be considered in the design of systems for safely transporting people seated in wheelchairs.

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## ACKNOWLEDGEMENTS

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# The Problem of Metaphor in Intelligent AAC Systems

**Mark Jones, Kathleen McCoy & Patrick Demasco**
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

**Abstract**

Intelligent AAC systems, which encode an understanding of language, cannot afford to ignore the problem of metaphor. Here we discuss the nature and promise of future AAC systems that handle some metaphorical statements. We describe the problems that metaphor creates for such systems, as well as a special class of metaphors called transparently-motivated metaphors, which are particularly important. Finally, we point to a possible solution to the problem.

## Background

The majority of present AAC systems use numerous techniques at the surface level of an expression to facilitate the communication of the user. More intelligent AAC systems of the future will be able to take advantage of an understanding of what meaning the user intends to convey in order to facilitate the communication of the user in ways that present systems cannot.

These more intelligent AAC systems are distinguished by having a deeper understanding of the expression the user wishes to convey. They must have some understanding of what is actually meant by the input from the user and the language generated.

These systems will rely upon advances from the field of Natural Language Processing (NLP). Techniques from NLP can empower a computer system to understand abbreviated input, track previous expressions, recognize communicative goals, and disambiguate expressions with the help of specified world knowledge. The goal is to have a computer system that can help a user communicate with insight similar to that of a human aid.

Example

Consider how one could understand, and perhaps rewrite in sentence-form, the ideas behind the abbreviated utterance "Buy 3000 Exxon." Several elements come into play here. The context could tell us whether this is a command or a question. Our knowledge that (unlike buying a pizza) Exxon is a company that can only be purchased in part, via stock, is important. Knowing that stocks are bought with money is also important. Finally, knowledge about the user's wealth would indicate whether 3000 shares or dollars is intended (if indeed it is a command to execute a purchase). The equivalent sentence may be "Buy 3,000 dollars worth of Exxon stock."

Complementing existing technology

The advances represented by present surface-level systems need not be replaced, but can be combined with the benefits of more intelligent AAC systems; they can work in tan‹ ı. For example, the Sentence Compansion System Demasco et al., 89, McCoy et al., 90) is designed to work in tandem with word selection and word prediction systems.

## Statement of the Problem

The knowledge that more intelligent systems are based upon must be specific (e.g., stocks are purchased with money, hammers are tools, windows are fragile) to be useful to a computer system.Therefore, it may be necessary for a system to require that metaphorical expressions be excluded. Otherwise they will be unable to behave adequately, and would fail their task.

This may at first seem reasonable, if the user wants to write poetry, the user should know that the more intelligent system should be switched off. Unfortunately, there is a class of metaphors that are not easily recognized as metaphorical (Lakoff and Johnson 80). We cannot expect the user to recognize the metaphorical nature of such expressions. These types of expressions are called *transparently-motivated metaphors* (Jones and McCoy 1992).

Expressions such as "Put $3000 into Exxon stock." occur quite often and, at first glance, may not appear to be metaphorical. However, the speaker does not literally put money into the stock, but rather buys the stock with the money.

Example

Consider how the system of the first example would handle "Put 3000 Exxon " Here we see where the traditional approach to er ling the knowledge breaks down. The system would quickly become confused because there is only one Exxon. Furthermore, Exxon is hardly the type of object that can be put somewhere. The highly structured knowledge may be quite powerful, but it is also very inflexible to metaphors, even those which we use without a second thought.

Consider just a few more metaphorical expressions that often pass without notice. "Savings and Loan bail out" and "Chrysler bail out," although salient at different points in recent history, appear to come from the same conceptual roots. In literal terms, an entity is in trouble, and is getting outside (government) help. The term bail-out that is used to describe this situation is hardly literal, and evokes the image of something more concrete. Finally, many of us have heard the progress of someone's career described in more concrete terms by saying something similar to, "it is moving {slowly / forward / backward}."

It might be reasonable to expect the user to avoid giving the more intelligent AAC system a blatant metaphor, however the cognitive load associated with recognizing transparently-motivated metaphors is unreasonable. We will need more robust solutions.

## Approach

In order to approach a solution to this problem, it is useful to consider why these metaphors are hard to recognize and are such a part of our language environment.

Our understanding of the world influences the way we express ourselves. Metaphorical expressions often reflect conceptual models which are the basis for how we understand the world. Mark Johnson (Johnson 87) has made some interesting observations about the building blocks of thought, most notably that the building blocks of thought are based closely to our bodily experience. Among the building blocks he has described are attraction, blockage, and containment.

This metaphor of "putting money into stock" is based in the simplifying concepts that represent investments as containers which can hold money. The metaphor of the S&L bail-out is based on the much more concrete situation of that of helping to bail out another's boat before it sinks into the water. The example of "a career moving slowly" suggests a background model in which people can view progress in terms of a moving vehicle.

When we write and talk we automatically use non-literal expressions that reflect our common conceptual groundings. These lead to very natural and easily understood expressions because we (speaker and hearer) share these common conceptual groundings. Because they are grounded in the building blocks of our thought, these metaphorical mechanisms and concepts can operate in our minds without our conscious knowledge of them doing so.

Our approach is to supply a more intelligent AAC system with the necessary conceptual grou...dings to understand/generate these types of metaphors. Doing this will allow a user to express ideas in a way that is most natural. This addition will allow metaphoric expression in places where the system's knowledge would previously allow only strictly literal statements.

### Metaphorical Domains

A metaphor maps between two domains. In the "putting money into stock" example, the finance domain is the *tenor* domain and the container domain is the *metaphorical* domain. Computationally, it is very useful to limit the number of possible metaphorical domains. Unfortunately a metaphor can potentially use anything as a metaphorical domain. However, in the case of transparently-motivated metaphors, we can be more specific about what can qualify as a potential metaphorical domain. We have recognized that they must be universal, concrete, and have specialized lexical expressions to clearly identify the domain (e.g., the expression *put in* identifies the container domain).

### Metaphorical Domain Selection Rules

Recall that earlier we discussed how conceptual groundings motivate transparently-motivated metaphors. The purpose of the metaphorical domain selection rules is to represent those concepts computationally. We envision rules that will embody the notion that "Stocks can be described as containers for money." Other selection rules would include: "arguments are often described in terms of war", "argument structure can be described in terms of buildings", and "progress can be described in terms of a vehicle moving toward a goal".

Each of these selection rules must have associated with it more specific mapping information. In the stock example, we would need to specify that it is the purchase price of the stock that is put into the stock. We would like such information to be general enough so it could also account for the meaning of "I moved $3,000 from Exxon to a money market account." Here, the concepts associated with *put* and *take* are both found in the verb *move*.

Consider the rule stating that progress can be described in terms of a moving vehicle. Included in (or derived from) the information closely attached to this rule should be the following:

| Tenor Domain | Metaphorical Domain |
|---|---|
| progress | forward |
| negative progress | backward |
| no progress | still |
| unsatisfactory progress | slow |

### Generating from More General Principles

We are excited about the potential for abstracting beyond the level of information presented above. Recall the "career as moving object" example. Note that the moving object has some starting point, some goal and some points on its path. With time involved, it also has some speed. It appears that with a sophisticated model of this behavior in the metaphorical domain and rules linking it to appropriate types of tenor domains, that the above four mappings could be derived. Interestingly, a more general structure matched with reasoning could yield other derived expressions. With the knowledge that energy is required to move objects, and given that a prototypical moving object is a car that runs on gas, we could hope to handle "My career is running out of gas" *without* an explicit rule for this occurrence. As the level of the information that motivates the metaphors reaches a higher level of abstraction, a greater degree of flexibility is anticipated.

Not all selection rules lie at the same level of abstraction. The selection rules, and their associated mapping knowledge may need to be encoded hierarchically. For example, the concept of possessions as containers of their purchase price may be a more specific version of the general concept that things are containers of what goes into their existence (e.g, "I put a lot of (time, energy, love, money) into this relationship!").

### Benefits

It would be undesirable for a more intelligent AAC system to attempt to handle metaphorical expressions without a model of metaphor. One might propose that in order to handle metaphor all we need is to relax some of the knowledge in the system. If nothing else fits, doubt the knowledge in the system about the words *put Exxon* and *3000*. Then, even though the system knows better, it can forget that restrictive knowledge and allow 3000 to be put into Exxon, without a sophisticated model of metaphor.

Unfortunately, this naive approach cannot work satisfactorily. First, if we merely relax, or doubt the knowledge in the system, we have little or no idea what the words mean. Such ambiguity would then cause such a system to merely try a great number of combinations. It would generate all kinds of expressions, perhaps: "Exxon has been put on top of 3000", "Put 3000 Exxons" and "Exxon has put 3000." Note that these examples occur while still assuming that the verb *put* is still the same, that only the properties of the other words are in flux. If the verb were also relaxed, even stranger constructions would be expected.

Second, the power of such AAC systems comes not only from their static knowledge about the world, but also from the dynamic knowledge that comes from tracking the discourse by understanding previous expressions. This discourse tracking would be diminished, along with the performance of the system, even if it were possible to generate the right metaphor without understanding it.

It would be different and more reasonable to consider ways to use lesser approaches to the problem if it were believed that the phenomena of metaphor was arbitrary with no identifiable structures behind it. Fortunately, the most important metaphorical problem to AAC systems, transparently-motivated metaphors, are based upon a firm structure, as has been described earlier. We do, however, need to do much more work on the problem of specifying the mechanisms behind transparently-motivated metaphors computationally.

### Implications

Since transparently-motivated metaphors are often produced without being recognized as non-literal, it is unreasonable to require users of future AAC systems to recognize them. Fortunately, the behavior of transparently-motivated metaphors is not arbitrary, and therefore can be incorporated into a more intelligent AAC system. This will allow for much better behavior of the system, lessen the cognitive load, as well as facilitate completely natural expression.

### Acknowledgments

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Mark Jones
Applied Science and Engineering Laboratories
A.I. duPont Institute
P.O. Box 269
Wilmington, DE 19899
Email: jones@udel.edu

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# EVALUATION OF A TEXT-BASED COMMUNICATION SYSTEM FOR INCREASING CONVERSATIONAL PARTICIPATION AND CONTROL

Norman Alm, John L. Arnott and Alan F. Newell
Department of Mathematics and Computer Science
University of Dundee
Dundee, Scotland, United Kingdom

## ABSTRACT

A prototype communication system has been developed which allows a non-speaking user to incorporate relatively long text segments into a conversation. The prototype has been developed with continuous participation in the design development by a potential user. The first trials of the system were conducted using a single case-study design. The trials evaluated the ease of use of the system's interface, and its ability to help the user increase participation in conversations, and also increase their control of the dialogue. The system was found to augment significantly the user's current communication methods.

## BACKGROUND

One important aspect of conversation which is very difficult for users of AAC systems to perform is the telling of extended narratives, or relating their views or experiences in the sort of detail which natural speakers find easy. Such conversational contributions increase the impact of the speaker's personality, and to control the conversation, rather than simply answering direct questions put by the other speaker, which is a conversational role that AAC users too frequently find themselves filling.

For an AAC user to make use of such conversational techniques, they would need to be able to store and retrieve easily a reasonably large amount of conversational material.

## RESEARCH QUESTIONS

Use of hypertext
Keeping track of a large amount of stored data, and retrieving it easily and quickly is a general problem in information technology. In the case of conducting a conversation, part of the task is to make conversational contributions on the current topic, and to be able to move on to other topics without breaking the sense of continuity which both speakers attempt to create [1]. An interesting research question is whether particular ways of structuring stored conversational material will help in modelling the way a conversation might proceed.

Involvement of user from beginning of design process
Another important research question lies in optimizing the interface between the user and a complex system. It is important that the cognitive load in controlling a conversation system should not be an additional burden on an already hard working non-speaking conversationalist. In this experiment we have explored the possibilities offered by software which allows the rapid building and altering of the interface, using an iterative design method, where a potential user becomes in fact a continual partner in the interface design, rather than just an experimental 'subject'.

Effect of introducing extended text into aided conversations
The third, and most crucial, research question was what effect would the use of a conversation aid which allowed the introduction of large amounts of spoken text have on the nature and quality of the dialog.

Previous research has examined the usability of a text database to store conversational material [2]. One outcome of this research is the need for the system to take a more active part than a traditional database in helping the user to access stored material. A promising approach is to have the system contain information about what the user is trying to accomplish, so that it may anticipate their needs [3,4]. The experiment reported here is the beginning of a project to explore hypertext as a suitable structure to achieve the ends described above. Hypertext is a structure which allows multiple links between text items, and as such, should offer a good structure with which to model within-topic conversational moves and topic shifts.

## METHOD

A prototype system was developed using the Hypercard software on a Macintosh computer, with output through a text-to-speech synthesiser. Implementing the system in Hypercard allowed for rapid prototyping of the interface, in keeping with the iterative nature of the design process. The system has been given the working name 'Floorgrabber', one of its intentions being to increase the user's conversational control. The interface design was a cooperative effort between one of the authors and a non-speaking person who had declared an interest in becoming part of an AAC research team. This person also was the user of the system in the trials. After experimenting with various interface types, a control panel metaphor was chosen. This allowed for a tightly packed display which was still clear in its layout, and meant that all the controls and displays could be put on one screen, with no need to to go to other screens or menus. The interface consists of text boxes and 'buttons' which are activated by pointing and clicking with a mouse. Three types of buttons were used. These had the effect of (1) speaking the text in the box pointed to (2) speaking a quick comment, (3) going to another topic.

Because the user of the system in these trials had been involved from the start in the system design, there was no need for a training period in using it. The user was a young man of 20, who has been non-speaking from birth through cerebral palsy. His usual method of communication is a 400 word Bliss chart, supplemented with a VOIS 135 communicator, plus gesture and some vocalisations. He has no receptive language problems, but significant spelling and syntax difficulties. He has a fair degree of controlled movement, and was just able to operate a mouse.

For this first experiment, the user produced textual material about one topic, a journey abroad he did for an international swimming competition. This topic was chosen because he is often asked about this interesting experience. Using his traditional communication modalities, he conveyed to a volunteer anecdotes and comments about the journey and competition. As he communicated, the volunteer stored this material into the system for him. The user's problems with literacy meant that this sort of mediation was necessary, but to ensure that the words were truly his, the material was all checked with him several times, and modified until he was completely satisfied with it as representing the way he would like to express himself.

The trials were conducted using a single-case experimental design. The user had 12 conversations with 12 different people on the chosen topic. The 12 sessions followed an ABAB pattern, with the baseline sessions (A) consisting of the user taking part in the dialog with his current communication methods, and the intervention sessions (B) differing by the inclusion of the prototype system as an additional mode of communication. Each conversation took 15 minutes. Half of the conversation partners were familiar with the user and had communicated with him using his current communication methods. The other half did not know him, and had no experience of communicating with an AAC user. The user's instructions were to use whatever communication mode was most comfortable and effective throughout the dialogs. The conversation partners were asked to have a 15-minute conversation with the user about the swimming expedition. All the dialogs were videotaped. Transcripts were made of the dialogs.

The information produced in this experiment is extensive: three hours of transcribed dialog. The first measure applied to the material was to assess the effectiveness of the prototype system, in terms of its ability to help the user take a fuller part in a dialog, and to have more control over the direction of the conversation. This was measured in two ways. Firstly, a count was made of all the words produced by each partner in the dialogs. Secondly, two conversational moves which were of relevance in conversational control [5] were defined :

RESPONDER : An answer to a question, or a feedback (backchannel) comment to the other speaker

INITIATOR : A question, or a statement which is not a responder.

All occurrences of these conversational moves by both partners in the transcripts were counted.

## RESULTS

Referring to the three research questions which were addressed :

Use of hypertext

The first stage of the prototype design has been to develop a usable interface and test the basic performance of the system. As the prototype grows in size, hypertext features will come into use in order to facilitate navigation through the material, and at that point the effectiveness of this structure will be assessed.

Involvement of user from beginning of design process

This provided helpful insights for the researcher, and allowed design problems to be addressed by continually checking the effectiveness of potential solutions.

Effect of introducing extended text into aided conversations

The results of an analysis of the transcripts are shown in the table below (Table 1), and the accompanying graphs (Figs 1,2,3). It is clear that, when the prototype was added to the user's communication modes, he was able to increase the total number of words he used in each conversation to a significant degree (t-test value of $p < .01$). (Fig. 1). The level of word output of the other speaker was unaffected, which indicates that the AAC user having the ability to introduce text did not inhibit the other speaker.

Conversational control by the AAC user was also increased, as measured by his increased use of initiators ($p < .05$). (Fig 2) Again, the natural speakers retained their level of initiators even when the AAC user increased his, indicating a dialog which was in general more lively. There was no statistically significant difference in the AAC user's level of responders, but the increase in the case of the natural speakers was significant ($p < .05$), which is not surprising, since the natural speakers had more opportunities to respond when Floorgrabber was in use (Fig 3).

| | Without Floorgrabber | With Floorgrabber |
|---|---|---|
| Mean number of words | | |
| Natural speaker | 917 | 999 |
| AAC user | 143 | 534 |
| Mean number of initiators | | |
| Natural speaker | 48 | 50 |
| AAC user | 10 | 27 |
| Mean number of responders | | |
| Natural speaker | 19 | 36 |
| AAC user | 87 | 71 |

Table 1 : Summary of measures taken with and without Floorgrabber

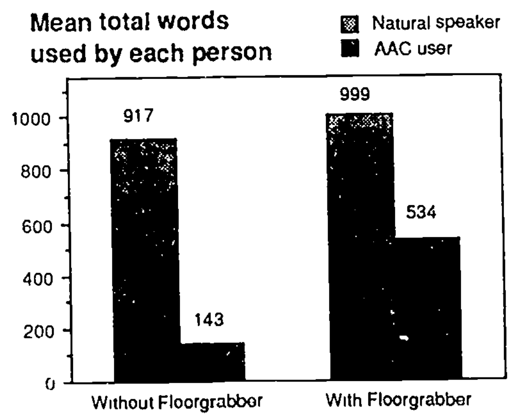


Figure 1

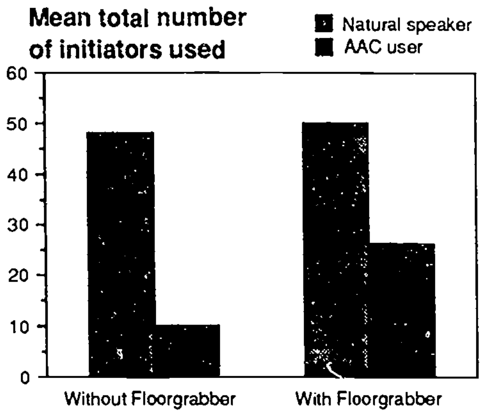


Figure 2

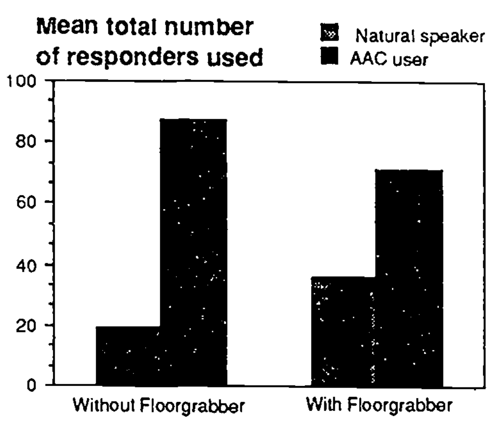


Figure 3

## DISCUSSION

This is the beginning of a series of analyses to be performed on the material produced by the experiment. Although at a very early stage, this data indicates that the system shows a promising direction for increasing the communicative repertoire of AAC users. In addition to further analysis of the data produced, work is proceeding on a further extension of the prototype, to cope with multiple topics.

## ACKNOWLEDGEMENTS

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Norman Alm
Department of Mathematics & Computer Science
University of Dundee
Dundee, Scotland DD1 4HN
United Kingdom

# AN INTEGRATED PRECICTIVE WORDPROCESSING AND SPELLING CORRECTION SYSTEM

Andrew G.Wright, William Beattie, Lynda Booth, Ian W. Ricketts & John L.Arnott
MicroCentre, Dept. of Mathematics and Computer Science,
University of Dundee, Scotland, UK.

## ABSTRACT

This paper describes the development of a predictive wordprocessing system with an inbuilt spelling corrector, designed for users with dyslexic-type spelling disorders. The system was created by the amalgamation of two previously existing systems, and is currently undergoing preliminary trials in the school environment.

## BACKGROUND

The authcrs have been involved in the creation of two previous systems designed for users with a variety of written communication difficulties: firstly PAL (1), (2), a predictive wordprocessing system now available commercially, and secondly Speller (3), (4), a spelling corrector with the capability of finding phonetic misspellings. Previously, users would employ PAL to create a text file, and then exit the PAL system and use Speller to correct this file. It was decided that, if possible, a superior mode of operation would be to integrate the two systems into one unit, so that the Speller system could be used from within PAL.

## PROBLEM STATEMENT

The two components of the desired integrated wordprocessing system were already present in a tried and tested form, so the main problems were the successful passing of data between the two programs, and the technical difficulties that would be likely due to the large memory usage of both systems.

## RATIONALE

The integrated system would have significant advantages over the previous operational mode of using one system and then exiting to the other. These are:

i) greater convenience to the user

ii) the system would be able to provide on-line help

iii) no incorrect words could be passed to the PAL dictionary during normal run-time operation.

It was also felt that the integrated system would be a considerable improvement over existing wordprocessing systems for the potential client group. The benefits of PAL as a text entry system have already been demonstrated (2), and similarly the superior performance of Speller when tested against commercial spelling correctors on samples of misspellings has also been reported (3), (4).

## DESIGN

The integrated system was designed to operate on a range of IBM PC-compatibles, in particular portable computers with clock speeds of 12 MHz or above. The clock speed requirement was due to the large amount of processing that would be necessary. Experiments with 4.77 and 8 MHz machines had shown that the system was likely to be too slow to have a value at other than the prototype level at these clock speeds. The system would be required to incorporate the maximum number of facilities from both PAL and Speller, particularly the frequency and recency statistics for all the words in the PAL dictionary and the lexical and phonetic word-matching capabilities, and inbuilt error logging facilities from Speller. As a method of reducing the memory requirement of the integrated system, the PAL and Speller dictionaries were merged. Visually the program was designed to be as similar to the PAL system as possible. The Speller part of the program was to be effectively 'invisible' until a spelling error was encountered, when the error would be highlighted on screen, and a window would appear below it as in Speller, containing the list of suggested corrections.

## DEVEL OPMENT

The PAL system needed to have a method of transferring data to Speller for examination. It was decided that the simplest mechanism would be that the user would employ PAL to enter text as normal, and that, on the completion of a word in the text, Speller would be activated. A word was considered to be completed when the space key or any other standard terminating character was entered, or when a prediction was selected from the PAL window. Because PAL offers word endings as predictions e.g. '-ing', '-ed' when it is unable to find any appropriate words in its dictionary, selection of a PAL prediction does not necessarily guarantee that the word has been correctly spelt. Speller was therefore activated at all points where a word had been completed. Firstly, as PAL is a memory-resident program, which takes over the keyboard interrupt, this interrupt is redirected to the standard keyboard handling procedures. Speller then scans through its dictionary searching for the entered word, and forms a list of suggested corrections if a match is not found. If the word is found in the Speller dictionary, a return is made to PAL with the word unchanged. If a list of corrections is produced, the word can be corrected by the user using the Speller menu. The correction is then passed to PAL. Finally the PAL interrupt is restored, so the overall effect is that any required corrections

are made without affecting PAL in any way other than by altering the incorrect word.
A small enhancement was made to the Speller part of the overall system by giving it the facility to examine misspellings to check if they were actually two words joined together as one e.g. 'thisis' being a misspelling of 'this is' as opposed to a misspelling of 'thesis'.

## EVALUATION AND DISCUSSION

The merging of the dictionary structures, mentioned earlier, also created two additional possibilities that were incorporated into the overall system.

i) the use of word frequency and word recency data to influence the compilation of a prediction list of corrections for misspellings;

ii) PAL could be given the capability of producing phonetically based predictions e.g. offering 'physics' as a prediction after the letter 'f' had been used at the start of a word.

Evaluations of PAL and Speller had already been conducted which showed they had significant value as a predictive system and a spelling corrector respectively. As an initial evaluation of the prototype integrated system, it was give to a teacher for use with three children, and the logged data produced examined on a regular basis. The Speller part of the system performed at the level that would be expected from previous trials (3), (4). Reported advantages of the overall system were the benefit to the users of having an interactive on-line spelling corrector within the wordprocessing environment, and the increased accuracy of the content of the PAL dictionary structure. A further advantage of the integration process is the ease with which the Speller dictionary can be personalised by the individual user.

## CONCLUSION

A predictive wordprocessing system and a spelling aid, both designed for users with severe spelling disorders, have been successfully integrated. The benefits of each individual system have been maintained in an overall system which offers considerable help to this type of user in the accurate and speedy generation of textual output.

## ACKNOWLEDGEMENTS

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Andrew G. Wright,
MicroCentre,
Dept. of Mathematics and Computer Science,
The University,
Dundee DD1 4HN,
Scotland, UK

# Flexible Abbreviation Expansion

Gregg M. Stum, Patrick W. Demasco
Applied Science and Engineering Laboratories
University of Delaware / Alfred I. duPont Institute
Wilmington, Delaware USA

**Abstract**

This project is part of an augmentative and alternative communication project directed toward reducing the burdens imposed on both clinicians and users by traditional fixed abbreviation expanders. These burdens include the requirement to devise and memorize good unique abbreviations for the items that are to be abbreviated. This is achieved by the application of a set of formal abbreviation rules across the user's vocabulary in order to anticipate the abbreviations that the user will enter. A flexible expander is currently under development for the Microsoft Windows operating environment. Being independent of any particular application this expander offers consistent access to abbreviation expansion from within any context.

## Background

Ever since [KV82], abbreviation expansion has been identified as an important technique to reduce the typing load of individuals for whom typing is their primary form of communication, or for whom typing is a significant physical task. It is important for these individuals to produce text as quickly as possible and with the least possible effort.

Abbreviation systems developed since then rely on the assignment of a specific unique abbreviation to each word that the user wishes to abbreviate. The user then enters this abbreviation and the system replaces it with the associated expansion. This approach is easy to implement and operates efficiently.

Unfortunately fixed abbreviation expansion imposes numerous unnecessary burdens. The user is required to memorize all of the abbreviations that the system recognizes. Someone must manually devise and enter any abbreviations not already in the system. The set of abbreviations is probably not optimized for the cognitive skills of the user.

In Word Compansion [DLM89] there is no predefined assignment of abbreviations to expansions. Rather, the system performs a number of transformations on an abbreviation in attempting to infer the intended expansion. In this way the user simply enters a reasonable abbreviation for the expansion they intend, rather than recall one that they had memorized.

Flexible Abbreviation Expansion is thus a hybrid of these two approaches. It uses knowledge of how people go about abbreviating in order to anticipate the most likely abbreviations that a user will enter for any given expansion. This allows it to operate as efficiently as traditional fixed expanders while bringing the power and flexibility of Word Compansion to the user.

## Statement of the Problem

Current abbreviation expanders succeed primarily in decreasing a user's typing load. Ideally this also translates into increasing the rate at which the user produces text. While just this is of tremendous benefit, there is still room to significantly improve the user's typing capability.

The first improvement is to free the user from memorizing specific abbreviation assignments. Current systems do decrease the amount of memorization required of the user by utilizing mnemonic coding approaches to make the abbreviation assignments easier to remember. Typically these take the form of: <2>='to', <b>='be', <4>='for', and <bc>='because', and so forth. [V87][R91]. While such approaches work very well for the most common and frequently used items, the fact that they are still unique assignments means that once an abbreviation is used for one item, it is unavailable for any other item, no matter how good or appropriate it might be in that case as well

This leads to the second improvement being covering the user's broad vocabulary needs. Generally expanders come with a set of default assignments for common vocabulary items such as function words, articles, and frequent verbs, nouns, and phrases. These do comprise the majority of the user's typing needs; they aren't its totality. There is a vast reservoir of subject-specific vocabulary that the user taps on demand. To abbreviate any of these items with a current expander, someone must have manually assigned an abbreviation to it. Since any of these items are used infrequently, it is not practical to make the effort in coming up with abbreviations for each of these that are both unique as well as easy for the user to remember.

A solution to this need illustrates the third improvement, tailoring the set of abbreviations to the individual user. To overcome the demands of manually making the abbreviation assignments, one could consider using sets of predefined abbreviations; one for 'chemistry', one for 'basketweaving', one for 'golf', and so one. Two problems with this solution are not being able to insure the uniqueness of any particular abbreviation, and that the abbreviation assignments do not in general reflect the preferences of its user.

Another improvement is making abbreviation expansion available to the user within any typing context in a consistent manner. Currently an expander is tied to a specific application. If a user has an expander for a speech aid it is seperate and distinct from one they would use with a word processor. Not only must the user how to operate each of these, they must also remember a different set of abbreviations with each, or at least remember which and how the abbreviations differ.

### Approach

Flexible Abbreviation Expansion makes all of these benefits available to the user. It achieves this by using a set of abbreviations for a given expansion, rather than a unique assignment. This set is not entered manually, rather it is generated automatically given the set of items that is to be abbreviated.

An abbreviation strategy directs the generation of the set of abbreviations associated with a vocabulary. The strategy consists of a set of abbreviation rules that are partitioned into subsets related to word length. That is, for a word of a specific length, there is a set of rules to be used in producing a set of abbreviations for that word. This set is ordered according to the user's preference in applying the rules. This arrangement is based on the observation that preferences vary among individuals based on word length [S91].

An abbreviation rule is a formal description of the relationship between an expansion and an abbreviation [S91]. A simple example is truncation, where the abbreviation is some number of the leftmost letters from the word. Another example is salient-letter, the first letter of each syllable in a multiple-syllable word.

Once the set of abbreviations is generated, they are entered into an abbreviation-expansion table. Each row of this table represents all of the expansions for any particular abbreviation. These expansions are ordered by the preference for the rule used to produce the abbreviation. That is, the most preferred expansion is the one for which the abbreviation was produced by the most preferred rule. When two expansions have the same preference, they are arranged by increasing length. This represents the preference of having shorter abbreviations associated with shorter expansions.

The entire set of items that the user wishes to abbreviate is divided into seperate vocabularies, where each is typically a set of perhaps as many two hundred related words. The user can then select a small number of these vocabularies as being active at any given time. This allows the expansion to focus on the particular subject about which the user is writing, rather than the as many as twenty thousand words that the user might know in general. Each such vocabulary has its own table. This is done for the convenience of the user and makes the process of expansion more efficient.

The user has a choice in how abbreviations are expanded. With one method the abbreviation is replaced with its most likely expansion. Should this not be the one that the user intended, they press the Space Bar (or any designated <abbreviate>key) again, and the next most likely expansion appears. The user repeats this, cycling through the entire list at will, until the desired expansion appears, at which point they resume typing with a non-<abbreviate>key. With the second method, should the user reject the most likely expansion, a list is presented from which the user can select the desired expansion directly. These expansion methods are actually not distinct: the user can press the Space Bar to scroll through the list, and can directly select the expansion in the first method. The difference between the two is essentially whether or not the list appears when the most likely expansion is rejected. This is provided as a feature for those users to whom the seeing the list is not of benefit.

One important observation about flexible expansion is that it does not preclude the traditional fixed expansion. The table produced for any vacabulary can be edited to add, change, or remove both abbreviations and expansions. In this way fixed abbreviation assignments can still be used by simply having only one possible expansion for an abbreviation. Thus the expander can provide the benenfits of fixed expansion for the most frequently used items.

**Implications**

By removing the uniqueness constraint on the abbreviation-expansion relationship, the user no longer has specific assignments to memorize. Rather, the user can simply construct some reasonable abbreviation for the expansion item they wish to enter. With a suitable defined strategy the expander will have anticipated this abbreviation and can present the desired expansion. In the worst case the desired expansion would be one of the alternative expansions the system identified.

Using the strategy the system can tailor the set of abbreviations for a given set of items to any particular user. More importantly this set of abbreviations is automatically generated and does not have to be manually entered. Thus abbreviation expansion is made available across the user's vocabulary in a practical manner. Being independent of specific application, flexible abbreviation expansion gives the user consistent and transparent access across all applications. The user can make use of the same set of abbreviations in the same manner from within any application and gain the same benefit.

**Discussion**

A flexible abbreviation expander is being developed and tested for the Microsoft Windows environment. This typing aid gives users easy and consistent access to a wide varitety of software ranging from popular off-the-shelf word-processing to specialized speech communication. In addition, this is one more tool in making workplace accomodation more complete.

Future enhancements of Flexible Abbreviation Expansion includes incorporating adaptiveness to a particular user. Generally this means fine-tuning the operation of the expander based on the selection pattems of the user. For example, with a given abbreviation the user may actually prefer an expansion that the strategy indicates as being the third most preferred. An adaptive expander would recognize this and override the strategy and reflect the user's preference with this abbreviation. In another case, the system could also observe more wide-scale tendancies and actually modify the strategy itself. Of course, some users will be more sensitive to this fine-tuning than others. So the use and extent of adaptiveness would be entirely at the discretion and desire of each individual.

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**Contact**

Gregg M. Stum
Applied Science and Engineering Laboratories
A. I. duPont Institute
PO Box 269
Wilmington, DE 19899
Email: stum@asel.udel.edu

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# QUARTERING, HALVING, GESTURING: COMPUTER ACCESS USING IMPRECISE POINTING

Jutta Treviranus
The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario

## ABSTRACT

This paper discusses the development of several on-screen keyboards which can be controlled using imprecise or inaccurate pointing. These keyboards are modelled on presently available coded input techniques, such as Morse code or Etran systems, but use the dynamic nature of the computer screen to eliminate the need to learn a code. The use of simple, location-specific head gestures to indicate selection is also described.

## BACKGROUND

Presently, there are few commercially available computer access systems which effectively exploit the abilities of users who have limited pointing abilities or who are unable to time their actions. These users must accept less than optimal speed or accuracy due to present technical limitations. Users must frequently choose between direct selection or scanning. Many individuals who are presently using direct selection techniques do so with great effort and frequent errors. Accuracy can be improved at the cost of increased physical effort and decreased speed by strategies such as a key delay which forces the user to hold down the desired key longer, key guards, or larger spacing between keys. The alternative, scanning, is extremely slow and indirect. Another limitation of scanning is that young children frequently require an access technique before they can conceptualize the operational demands of scanning input (Kraat, 1987; Light, 1990).

Three approaches are suggested that bridge the gap between direct selection and scanning. One approach is to combine direct selection and scanning in one device. Thus, users would directly select to the extent of their abilities, and then scan to choose items which they are unable to select, or select from a larger group and then scan items within that group (hybrid selection)(Treviranus, Shein, Haataja, Parnes & Milner, 1991). This approach is not offered in any commercially available device at present but is frequently practiced by graphic communication display users and their communication partners. Another approach is to use a form of coding where two or more direct selections are used to choose each item. The sequence of actions required to choose an item could be either cued or memorized. In the third approach, termed disambiguation, the user chooses a group of items and relies upon the computer to guess (or disambiguate) which item within the group is intended. Thus the user makes only one direct selection to choose each item, unless the computer has "guessed" wrong. This paper will discuss the coding approach and the reconceptualization of this approach to accommodate the needs and skills of individuals with imprecise or low resolution pointing.

### *Present Applications of Coded Access*

The most common code is Morse code. Although Morse code is a potentially fast and efficient means of computer input several factors restrict its use by children with congenital neurological impairments. Users must reliably control the timing of one or two actions, to distinguish dits from dahs and to enter all elements of the code within the allotted time. The training requirements of Morse frequently restrict its use because it depends on the user's ability to memorize the code (Beukelman, Yorkston, Dowden, 1985). Systems less dependent on literacy are frequently chosen when users cannot read (Lee & Thomas, 1990). Even when the codes are reassigned to symbols, children frequently have difficulty in understanding the operational demands. Vanderheiden, 1984, proposed a selection technique which uses three reliable actions without the timing requirements usually associated with Morse code (three-switch Morse code). The Handicode™ software program uses this strategy. This technique requires three reliable switch sites and does not overcome the training demands of Morse code. Replacing the mnemonic cues with visual cues as implemented in the RealVoice™ reduces the need to memorize the code. The choices are presented in a binary tree structure, the user guides the cursor to the selection by activating the appropriate switch at each branching. Unfortunately the perceptual and visual-motor demands of this approach frequently outweigh its advantages.

In another form of coding users point with their eyes to a group of items on an eye-gaze frame (Etran), subsequently indicating which item is intended within the group by gazing to another group which indicates the location, colour or number of the item (Beukelman, Yorkston, Dowden, 1985). Clinicians report that this is an efficient selection method whose primary limitation is the listener. It is reported that even trained listeners are unable to keep up with skilled users. The Etran is infrequently used because the augmentative communication user is dependent upon trained listeners and because of the physical barrier an Etran frame creates between the individual and the listener (Trefler, Crislip, 1985). An electronic system modelled on the Etran is the EyeTyper Model 200.™ This unit displays eight groups of eight items. The user must gaze at the appropriate group and then at the group which corresponds to the position of the desired item. The display remains static. The gaze is detected remotely by a built-in camera system (Brandenburg & Vanderheiden, 1987).

Several researchers have explored a coding system for users who can accurately target to a telephone keypad. Three letters of the alphabet are assigned to each of nine keys. The simplest application of the keypad requires 2 keystrokes to select each letter (Witten, 1982). The user selects the key to which the desired letter is assigned and then one of the remaining three keys to indicate which of the three letters is intended.

Researchers have demonstrated that selection strategies such as those used with Etran systems are potentially far more efficient than scanning (Goodenough-Trepagnier, 1980; Vanderheiden, 1984). None of the above described coding systems, however, offers the conceptual simplicity of pointing. In each of the coding strategies the user does not point directly to the choice but also to another target which forms a code for the desired item.

Use of present coding systems is restricted due to one or more of the following reasons:

- the initial training demands are high because the user must learn a code,
- the system is based on traditional orthography,
- the user must be able to time their response, or
- the possible controlling actions monitored by the device are limited.

## STATEMENT OF THE PROBLEM AND RATIONALE

A selection technique which can be effectively controlled through inaccurate or imprecise pointing is required. This technique must offer relatively fast, efficient, accurate and simple control of computer based applications.

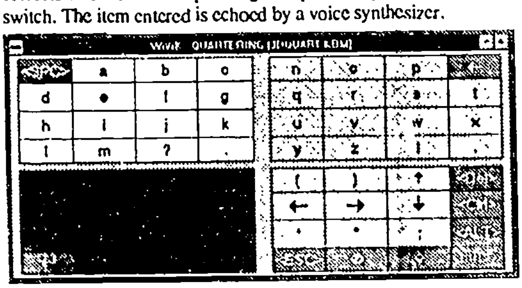
In order to provide such access for individuals with imprecise pointing the selection technique must meet a number of clinical criteria. Once the user has decided what to select the time taken to communicate that choice should be as short as possible. During this period the user usually works out how to communicate the choice to the system (the operational requirements), performs the required motor acts, and waits for the system to respond or present the desired choices. The system can be designed to make each of these tasks less effortful or quicker.

- The difficulty of the motor act can be more important than the number of motor acts required to indicate a selection.
- Error correction should be as simple as possible. There should be no opportunity to make additional errors in the process of correcting an error.
- Light, 1990, argues that the access systems must respond to the conceptual models of consumers. System representations and operational requirements should be in synchrony with the user's mental models. She also argues that the system should provide clues to designate the operational requirements. The "relationship between the user's goals and the actions required to achieve these goals" should be clearly designated by the design.
- The system should accommodate the needs of both the novice and the expert user. The system should be operable with minimal initial learning. The process of controlling the selection technique should become automatic or habituated as the user gains expertise. The system must therefore be very predictable and require minimal visual vigilance.

## DESIGN AND DEVELOPMENT

Several on-screen keyboards for imprecise pointing have been developed. These keyboards are modeled on the ETRAN but utilize the dynamic nature of the computer screen. The keyboards are implemented in an on-screen keyboard program called WiViK. The program runs on any IBM or compatible computer running Windows 3.0 or 3.1. WiViK can be addressed with any mouse compatible pointing device including head pointers or touch screens (Shein, Hamann, Brownlow, Treviranus, Milner and Parnes, 1991).

The first keyboard developed is a simple quartering keyboard. All of the selectable items are divided into four quadrants. The user points to the quarter containing the item they want. That quarter expands to fill the whole keyboard and is again divided into four quadrants. The user then chooses the quarter containing the desired item as before and that quarter expands to display one item per quarter. The user then points directly to the desired item. Thus a user who can only point to four targets can accurately pick one of 64 items with three selections. Each selection act involves locating the desired choice and pointing to it. (See Figure 1). The user corrects errors or backs up through the process by activating a switch. The item entered is echoed by a voice synthesizer.



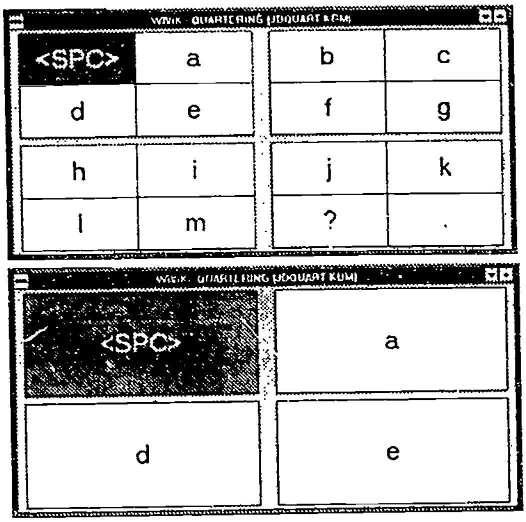



*Figure 1: Sequence of displays with quartering-style on-screen keyboard*

This keyboard was tested by several users who pointed using an absolute headpointer. It was found that vertical and horizontal head movements were easier to control than diagonal head movements. To allow control through vertical and horizontal movements the keyboard was redesigned. The keyboard was rotated to form a diamond, thereby maintaining the effect of expanding quadrants (See Figure 2).

When using a headpointer or other pointing device users indicated a selection by pressing a switch, vocalizing (to activate a sound switch) or pausing over a square for a predetermined time (dwell time). Switch activation frequently caused the pointer to stray from the target. When using dwell time users were more prone to make unwanted selections, often when the user was resting between selections. Some users had difficulty in maintaining the cursor on the target. To account for this an averaging feature was incorporated into WiViK such that the dwell criterion can be met by passing over the target several times.

Another solution exploits both the form and location of head or hand gestures. Each quadrant of the diamond is bisected with a vertical or horizontal line. To select the quadrant the user passes over the line and back into the center of the keyboard. The desired item is therefore selected by a series of three horizontal and/or vertical head movements. The size of the movements required can be adjusted by moving the lines further from the middle of the keyboard.

These quartering keyboards require three selections to choose each item. In order to make more frequently chosen items easier to select a variation of the quadrant keyboard, modelled on Morse code, was developed. Selectable items are divided into two quarters (those beginning with a dit and those beginning with a dah). The remaining quarters contain a space and a backspace respectively. When a quarter is chosen the priority item within that quarter moves to the quarter previously occupied by the space and the remaining items in that quarter are divided into those which require a dit and those which require a dah as the next entry in the code. Space and backspace can therefore be chosen with one selection. High priority letters such as e or t can be chosen with two selections. The selection technique emulates three-switch Morse code without requiring the participant to memorize the code.

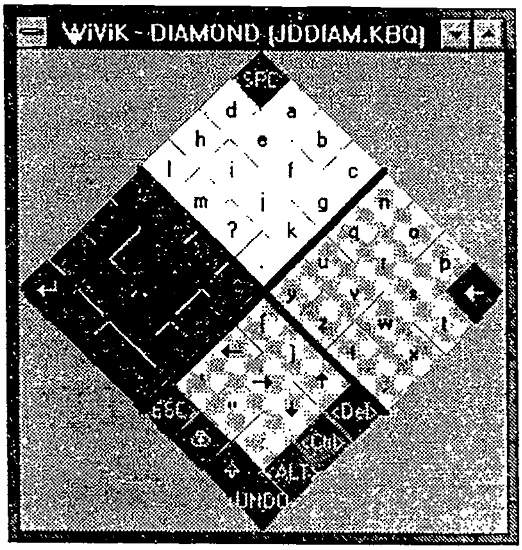



*Figure 2 : Diamond-style on-screen keyboard*

## EVALUATION

Users of these alternative access techniques have been actively involved throughout the iterative design process. The five clients participating in the evaluation have impaired pointing abilities due to cerebral palsy and are between the age of 7 and 27. These clients previously used scanning or expanded keyboards (with excessive effort or error). The pointing resolution of these individuals ranges from 4 targets to 8 targets when using an absolute head pointer to point to a standard sized computer screen. These individuals were able to grasp the operational requirements of the on-screen keyboards following a brief verbal description and a one minute demonstration. The quadrant and diamond keyboards were more formally pilot tested by two users resulting in the design adjustments discussed previously. When comparing entry using scanning with entry using the quartering technique, input rate improved from an average of 1.4 entries per minute with a standard deviation of 0.3 to an average of 3.1 entries per minute with a standard deviation of 0.4. These keyboards will be tested and further developed in a research study comparing 4 selection techniques namely: scanning, Morse code, quartering and disambiguation techniques.

## DISCUSSION

All permutations of this approach have not yet been explored, the development and evaluation process is expected to continue over the next few years. In considering the clinical criteria discussed previously these selection techniques appear promising for individuals with imprecise pointing abilities. The operational requirements of the developed selection techniques closely match the most natural method of selecting objects: pointing to them The task can be presented to the user as: "point to the one you want until it is entered." The expanding quadrants communicate the effect of bringing the desired item closer to the user. To match the necessary motor acts to the motor skills of the user the size and number of the targets can be adjusted. Unlike traditional applications of Morse code the user need not learn a code to begin to use the on-screen keyboards. The keyboards differ from disambiguation techniques in that they are very predictable and do not require the same vigilance to system errors or wrong guesses. They are therefore conducive to motor habituation. As the user becomes expert in using the keyboard the visual cues can be faded, perhaps ultimately leaving only the outline of the squares or lines to cross. Disambiguation techniques depend upon linguistic information to guess which targets are intended, the quartering approach is not dependant on linguistic information and can therefore be used outside a text application to select icons or other graphically represented objects.

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## ADDRESS

Jutta Treviranus
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, Ontario

# Laser Diodes for Head Pointing and Environmental Control

William A. Hyman, Gerald E. Miller, & Joseph S. Neigut
Bioengineering Program
Texas A&M University
College Station, Texas

## Abstract

Head mounted, light pointers have been used for some time as a means of communication. The traditional units have been incandescent resulting in mounting difficulties, high energy use, focusing/spot size limitations, and difficulty in use in high ambient light levels and over long distances. The visible light, diode laser offers an attractive alternative including small size and weight, low energy requirements, and a small, intense spot which can be seen over large distances even under high light levels. The laser based pointer can be used to indicate selections from both close and far targets without refocusing. The beam can also be used for environmental control applications as an input to an appropriate light sensitive switch.

## Introduction

Head, neck and eye movements provide a degree of motor control that can be effectively used by the non-verbal population with little or no use of the extremities (Brown, Kostraba, et al, 1991). This can include direct eye gaze communication, eye gaze monitoring devices for computer input, and direct activation of switches by the head, or with a head mounted mechanical pointer. It can also include head mounted visible light sources used as pointers (Field, 1991), and head mounted infrared (IR) sources for activation of IR sensitive devices. In the latter case visible light systems are sometimes also used for targeting since the location of the IR beam cannot otherwise be found. Commercial versions of such devices are available from a number of vendors.

The traditional visible light pointer has used incandescent light sources. These devices have been relatively large and heavy, and mounting them on the head has presented difficulty, although effective solutions have been reported (Field, 1991). The incandescent devices have other limitations including difficulty in focusing the light beam to a desired diameter, and maintenance of that diameter over variable distances. Light intensity has also been a problem in that high ambient light levels can wash out the beam. These problems can be very effectively addressed by the use of solid state diode laser modules with output in the visible domain (typically a red beam with a wave length of 670 nm). These modules, with appropriate drive circuits, optics and power supplies, produce a narrowly focused beam of high intensity. In our application a spot size of 1/8 inch is obtained over continuous distances from close to the source to across a room. Moreover they are light and therefore easily mounted, and their power requirements can be met by standard batteries.

## Laser Technology

"Laser" is an acronym for "light amplification by stimulated emission of radiation". The laser beam is characterized by being coherent (all light waves in phase) and monochromatic (one wave length/color). Laser beams in most applications have very little divergence, i.e. the diameter of the beam remains constant over large distances. In many applications this is particularly useful in that all of the energy contained in the light can be delivered to a small area. Lasers are characterized by the frequency of the light and the total power in the beam. In the visible spectrum frequency determines color, thus the red beam used in our device is light at a wave length of 670 nm). Some applications of lasers use beams that are not visible, i.e. ultraviolet or infrared. The power contained in the beam is very important with respect to the capability of the laser to cause damage to materials which the beam falls on. Other important parameters are whether the beam is pulsed or continuous, and the duration of exposure. High energy lasers can be used to cut even metals for example, and medical applications include the ability to cut and vaporize tissue. The eye is particularly sensitive to laser radiation and the destructive capability of lasers must be taken into account in all applications to provide assurance that inadvertent exposure to the laser beam will not produce injury. For safety and regulatory purposes visible lasers (frequencies of 400 to 700 nm) are divided into the classes shown below on the basis of delivered power (ANSI, 1986; 21 CFR Part 1040).

| Class | Power |
|---|---|
| I | < .01 mW |
| II | > Class I but <= 1 mW |
| IIIa | > Class II but <= 5 mW |
| IIIb | > Class II but <= 0.5 W |
| IV | > 0.5 W |

Engineering and personnel control measure requirements vary by class. Notably eye protection is required for Class IIIb and above so that such lasers would be unsuitable for use as pointers in general population environments. Class I lasers are too weak for practical use as pointers. Therefore suitable devices lie in Classes II or IIIa. The Class II lasers we use are sufficiently bright that it is reasonable to restrict this application to this class, rather than use Class III devices with their somewhat greater risk. However, by Federal regulation of laser products, Class II lasers require a warning label stating "Laser Radiation - Do Not Stare Into Beam" (21 CFR, Part 1040). Momentary eye exposure to a Class II laser beam is not considered harmful.

Early lasers were relatively large and complex devices with glass tubes and high input electrical power requirements. These limitations made these devices unsuitable for the present application. More recently the laser diode has become available (e.g. Toshiba TOLD 9200 or Sharp LTO20MD) in small and durable units. These diodes require a drive circuit, a colomating lens and a heat sink, along with appropriate input power of less than 5 volts. These devices are in common use in CD players and in hand held presentation pointers.

Head Mounted Laser Pointer

For the present application a complete laser diode module consisting of diode, drive circuit and heat sink is used for head mounting, while the batteries and power conditioning circuit are contained in a small box attached by coiled wire. This configuration is used in order to not have to carry the weight of the batteries on the head mounted unit. In addition the use of a 9 volt battery provides adequate duration of continuous use while taking advantage of the availability of project boxes for the power supply which include an externally accessible compartment for a 9 volt battery. The voltage regulating circuit produces a constant voltage of 4 volts which provides a useful beam which is well within Class II. The head mounted unit is attached to the ear piece of the user's own glasses or to lenseless eyeglass frames for user's who do not otherwise where glasses. The original design included in the mount the ability to independently aim the laser, but this was subsequently found to be unneccesary since direct attachment to the ear piece of the eyeglass frame puts the beam in a useful, more-or-less central position. The aiming mechanism was therefore eliminated. For most users the eccentric weight of the laser module on the glasses is not a problem. However for some users an elastic eyeglass athletic strap is used to help secure the glasses on the users head. When used alone the laser pointer provides an excellent light source for selecting items from a lap board word or picture menu. It can also be used for indicating selections over greater distances, including across the room as desired. The coiled cord is a convenience feature which eliminates trailing cords while providing protection from pulls on the wire. Our current units have a manual on/off switches on the power supply box which is used by attendants. Alternatively a separate head accessible switch could be provided so that the user could turn the laser unit on and off as needed.

Environmental Input

The fact that the head mounted laser provides an easily seen, well focused beam at great distances allows the laser light to be used as input to a light sensitive switch which in turn can operate any device to which the switch has been interfaced. We have constructed switches suitable for either battery powered DC devices (radios, tape players) or line powered (110 volt) devices (lights, televisions). The time delay portion of the circuit is to prevent rapid on/off switching during target acquisition. Our initial devices used solar cells as the detector in order to provide a large target. However, the narrow beam allows for small detectors and therefore a multi-target switch could also be easily made.

Classroom Use

The head mounted laser pointer provides a technology that could find interesting application in the classroom with properly prepared materials. The basic concept would be for the teacher to provide multiple choice answers for the subject being studied that are visible to the students. When a student response was called for the non-verbal student could use the visible light pointer from their seat to indicate their choice across the room, such as written on the blackboard. In fact the materials could be prepared for overhead projection since the laser light beam is easily seen even against the bright light of the overhead projector. Non-verbal children with upper extremity use could communicate similarly by just using readily available hand held pointers. Moreover, in the integrated classroom other student could also have laser pointers and a "silent" lesson could be given in which all participants responded by using their pointers.

Conclusion

Low power laser diode technology makes it possible to provide a next generation of head mounted visible light pointers. The units we have provided are in great demand and nearly continuous use by the recipients who are non-verbal adults with significant motion deficits such that head control is their primary useful physical function. These pointers are used for detailed communication from word/phrase boards, simple communication using pictures or objects, and for environmental control. These devices are a significant advance over incandescent pointers in terms of beam intensity, focusing, mounting, weight, heat, and power needs.

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William A. Hyman
Bioengineering Program
Texas A&M University
College Station, Texas 77843

# MAINSTREAMING STUDENTS WITH ASSISTIVE TECHNOLOGY

Molly Doyle, MS CCC, Cynthia Cottier, MA CCC, Ronna Joseph, OTR
CART Rancho Los Amigos Medical Center
7601 E. Imperial Hwy
Downey, CA 90242

**Abstract**

Students with disabilities often need assistive technology to participate in regular classroom activities. However, most regular education teachers have not received training in using assistive devices nor do they receive consistent support from personnel trained in this area. Currently, a pilot training program for "integration specialists" is being implemented in a local school district. Specialists train and provide support to teachers and their students who use voice output communication aids in regular classrooms. The beginning components of the pilot training program include information modules in the areas of: augmentative communication, seating and motor access, and interaction strategies.

**Background**

Students with severe speech impairments often depend on voice output communication aids (VOCAs) to participate actively in classroom activities. The prescribing clinicians provide students with initial training on their VOCA, but often cannot provide ongoing support due to large caseloads, time limitations and reimbursement problems. It is believed that ongoing support, in the form of teacher education and training in using VOCAs, significantly influences the extent to which students use their VOCAs in the classroom. When teacher training and support are lacking, the students' abilities to use their VOCAs to socialize with peers, to participate in class and to complete assignments is significantly compromised. This is particularly true for children using VOCAs in mainstreamed settings, that is, in classes containing predominantly able-bodied students.

To address the problem of insufficient teacher training and lack of support for students using VOCAs in integrated classrooms, this project proposes to develop and implement a training program for "integration specialists." The role of an integration specialist is to ensure that mainstreamed students have consistent access to activities in the regular classroom. Consistent access is achieved by training teachers and by maintaining communication devices.

**Objectives**

1. Survey professional groups and parents regarding services currently provided to students using augmentative communication systems, and the needs of students and their teachers in integrated classrooms.
2. Identify appropriate candidates for integration specialist training program;
3. Develop and field test training modules for integration specialist training program;
4. Develop and field test protocol that quantifies the interaction patterns among students using VOCAs with their teachers and classmates.

**Method**

Professionals and parents were surveyed to determine training needs of integration specialists. This information resulted in the development of several training modules which cover augmentative communication intervention as well as strategies currently implemented in classrooms to facilitate use of VOCAs. The modules include the following topic areas: Overview of assistive technology; Evaluating students and selecting augmentative communication systems; Seating, positioning and motor access to devices; Basic training in use of Touch Talker and Light Talker communication devices; and Training teachers to facilitate use of communication techniques. Each module has specific objectives, as well as pre and post tests to ensure that the objectives have been met. The training program is being pilot tested and will be modified based on feedback received.

A protocol is being developed to quantify and describe the interaction patterns among students who use VOCAs with their teachers and peers. The protocol will help to determine how effective integration specialists are in increasing both the quality and quantity of interactions involving device users.

**Discussion**

Due to caseload size, time limitations and reimbursement problems clinicians often cannot provide teacher training and device maintenance that students need to participate in regular classrooms. An "integration specialist," who acts as the liason between classroom members and the primary clinical team will significantly assist teachers in ensuring their students who use VOCAs have consistent access to activities.

The integration specialist will train teachers in the following areas: operating communication devices; assisting in curriculum adaptation; teaching able bodied students interaction strategies; providing students with disabilities opportunities to participate; and reinforcing the student's communication attempts. The specialist may assist the student and teacher in programming the VOCA and resolving equipment problems. The training modules teach the specialists how to provide these types of services. The modules were developed based on information obtained from the surveys and from clinicians' and teachers' experiences working with students using VOCAs in the classroom.

The specialists act as the liason between the classroom members (i.e. teacher, device user and able bodied students) and the primary clinical team. The specialist is trained to monitor those skills that influence the student's ability to communicate, and when appropriate, refer the student to the primary team for a followup evaluation. For example, the specialist may note that the student sometimes has difficulty activating his switch to control the VOCA. The student hits the switch with excessive force and after multiple attempts slips down in his wheelchair. In order to activate the switch successfully the student needs to be repositioned. The specialist would then contact the appropriate therapist to re-evaluate the student's wheelchair positioning and best method of switch access. The therapist would then make the necessary modifications.

The project has recently completed the first year of a 3 year study. The primary objective after completion of the pilot training program, is to finalize the training manual. The manual will be made available to school, hospital and university programs to assist clinicians in training staff as integration specialists.

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Molly Doyle, MS
Speech Pathologist
CART
Rancho Los Amigos Medical Center
7601 E. Imperial Hwy
Downey, CA 90242

# HYPERMEDIA AND THE CREATION OF KNOWLEDGE THAT TRANSFERS TO REAL-WORLD SITUATIONS: A REVIEW OF ANCHORED INSTRUCTION WITH SPECIAL NEEDS LEARNERS

Al. R. Cavalier, Ralph P. Ferretti, & Cynthia M. Okolo
Department of Educational Studies
University of Delaware, Newark, DE 19716

## ABSTRACT

Special education students often do not maintain and transfer instructed knowledge and skills. Research suggests that this is in part due to difficulty in distinguishing relevant from irrelevant information, a lack of requisite knowledge about the problem situation, and a failure to see the connection between the knowledge that is being learned and solution of the real-world problems. An approach labelled anchored instruction attempts to overcome these difficulties by using hypermedia-learning contexts that anchor skills to real-life situations. In systems using this approach, the critical distinction between information that is relevant and irrelevant to the solution of problems is highlighted. The acquisition of knowledge is enhanced by the use of rich databases that elaborate the student's understanding. And the conceptual "anchor" provided by a realistic story enables students to see skills as tools that have value in the solution of real-life problems.

## BACKGROUND

One of the most vexing problems facing special educators and rehabilitation counselors is their students' seeming inability to maintain and transfer the knowledge and skills that they've learned. Teachers wonder why students fail to use skills in situations that are similar to those in which they were taught. Small changes in the instructional materials, tasks, or instructions seem to undermine the effects of long and often arduous periods of training. So often, teachers know that their students possess the knowledge and skills that are needed for a particular problem, yet they do not use them flexibly and effectively. Children without obvious learning problems, and even students with exceptional talents, often experience the same difficulty. While it is found among all people, the problem is especially pronounced for children with learning handicaps (5) (8).

## STATEMENT OF THE PROBLEM

The reasons for the inflexible use of knowledge and skills are not fully understood. However, recent findings shed light on the problem. First, people respond to patterns that they recognize in the world. Relatively superficial characteristics of many problem situations are typically the most salient during problem solving. It is important, therefore, to structure problems so that students clearly recognize the important characteristics and their relationships to other problems that they might encounter (4) (9).

Second, people perform most successfully in problem areas in which they have acquired a great deal of information (7) (12). It is common to encounter children who possess a wealth of interconnected knowledge about such topics as dinosaurs, baseball players, rocks, cars, etc. Often, their memory for such details and the complexity of their problem solving in these areas stand in stark contrast to their performance in other situations. The specific knowledge that they possess helps them to quickly distinguish useful patterns of stimuli from irrelevant detail. This suggests the importance of encouraging children to develop their specific interests because the resulting knowledge can facilitate their problem-solving performance.

Third, skills and knowledge are too often taught as ends in and of themselves, rather than as a means to a larger end (2) (4). For example, math is often taught as a set of procedures that operate on mathematical symbols rather than as a tool for solving real-world problems. As a result, children often fail to see the usefulness of these skills in their everyday lives. Academic skills are little more than abstract puzzles imposed by adults on children for no apparent reason. As a result, it should not be a surprise that children fail to maintain and transfer skills under these conditions.

## APPROACH

A unique approach to instruction that addresses these factors has recently been documented in the research literature. This approach, called anchored instruction, is designed to overcome the tendency for children to be passive recipients of seemingly irrelevant information about unrelated problems (10). This is accomplished by creating rich instructional environments via multimedia technology that enable students to see how experts use skills and knowledge in real-life problem situations. To be successful in these problem situations, many different skills must be employed and coordinated. These rich instructional environments serve as conceptual anchors for learning about the interconnectedness of the different skills and their usefulness in solving real-life problems.

This idea of using real-life contexts to anchor instruction has a long tradition in education and is seen in such instructional arrangements as apprenticeships, on-the-job training, field trips, and laboratory experiments. However, these arrangements are not always possible to create, they often require an unwieldy amount of time, and they are often difficult to control to insure the desired instructional objective (3). Moreover, typically each of these individual situations are configured in such a way that they are conceptually isolated from each other. While each one provides a specific context for showing the real-life usefulness of a specific skill, they do not provide "macrocontexts" for learning about the interconnectedness of these skills in solving complicated problems.

Anchored instruction relies heavily on the use of hypermedia videodisc technology to create macrocontexts for learning. The laser videodisc provides vivid visual and audio information about dynamic events, enabling students to practice their skills in identifying relevant information and in developing rich mental images of problem situations. Moreover, the videodisc's random access capabilities allow teachers and students to quickly retrieve any information that they deem important for problem solving and to investigate "what if" hypotheses. Finally, more sophisticated videodisc players (technically known as Level 3 systems) can be controlled by computers and linked to databases of rich information, thereby enabling students to further elaborate their knowledge.

Dalton and Hannafin (1987), in a study that preceded the use of hyper-links and the term "anchored instruction", taught high and low achieving adolescents strategies for managing their personal finances when buying on credit. Using computer-controlled interactive video, they portrayed the problems caused by an inadequate understanding of the principles of buying on credit, such as overextending a credit limit, falling behind on payments, underestimating interest charges, and neglecting financial obligations because of excessive re-payment schedules.

The students were divided into three groups: those receiving Knowledge Training saw video scenes that depicted the basic concepts of buying on credit in the form of a narrator providing definitions. After each scene, the computer asked the student a definitional question that tapped his/her recall of the information. If the student's response was incorrect, the system replayed the video scene and asked the question again. Students in the Context Training group saw video scenes depicting the usefulness of the concepts in applied settings. The video followed an adolescent making a variety of financial transactions through the course of one week, such as negotiating the interest on a loan from his brother. After each scene the computer asked the student a question, but in this group the question was posed in the context of a real-world situation. Across the two groups, the questions were designed to tap parallel concepts. Each group proceeded through 10 instructional video segments covering parallel topics. Students in the Control group saw all video scenes, including both the definitional knowledge segments and the context-based segments, in a linear fashion, i.e., without interspersed questions from the computer.

All groups were then given two 20-item written posttests: one consisted of short-answer completion questions designed to tap recall of factual knowledge and the other consisted of short-answer completion questions designed to tap application of that knowledge. Students in both the Knowledge Training group and the Context Training group recalled more factual information than students in the Control group, although the two treatment groups did not differ significantly from each other. This finding substantiates the pedagogical value of actively engaging students in their learning. However, students in the Context Training group applied the knowledge from the lessons significantly better than the Knowledge Training and Control groups, who did not differ from each other. These results demonstrate that students are not able to effectively apply the basic knowledge that they learn unless that information is presented in a format that gives them opportunities for its application and in a context that anchors its utility to real-world situations.

Bransford, et al. (1988) taught children with math delays strategies for solving math word problems by using either traditional instructional methods or the macrocontext afforded by the movie Raiders of the Lost Ark. Interestingly, the first 10 minutes of this movie provide many good and vivid examples for teaching children measurement skills. By using the videodisc's random access capabilities, the researchers were able to isolate the sequences of frames that could be used to anchor children's understanding of measurement strategies.

Children in this study were given two pretests before receiving instruction. The first pretest assessed their understanding of measurement problems as posed in the traditional word problem format. The second pretest consisted of problems taken from the Raiders macrocontext. Not surprisingly, all children performed very poorly on both pretests. Children were then divided into two groups. Children receiving traditional instruction were given extensive practice representing the information given in the problem and generating solutions. They received corrective feedback about their efforts. Children receiving anchored instruction were given similar training but the problems were taken from the Raiders macrocontext. Children saw the sequence of frames that was relevant to the problem and received an explanation about its usefulness. They then generated their answer and were given feedback about the accuracy of their efforts.

Children in both groups were given two posttests that were similar to the pretests. The results were dramatic. Children who received anchored instruction were not only more accurate than children who received traditional instruction on problems taken from the Raiders movie, but they also were better at solving problems presented in the traditional word problem format. These findings demonstrate that macrocontexts can promote the transfer of problem-solving skills in children with learning handicaps.

Commercially-available videodiscs are a relatively inexpensive source for anchored instruction, but they have not been designed or produced with teaching and learning as a focus. Consequently, they often lack appropriate content for classroom instruction and fail to include information that is pertinent to a problem solution. To overcome these difficulties, Van Hanegan, et al. (1991) developed a prototype videodisc called The River Adventure. In this video, children are told that they had won the use of a houseboat and must make plans for a journey down the river. The video depicts a previous journey during which problems involving estimation and measurement were solved. The problems depicted in the video were relevant to the problems the children would have to take into account in their planning for their river adventure (e.g., volume of the boat's fuel tank, length of the journey, direction of the river's current). All of the information needed to solve the problems was either directly depicted in the video or could be deduced from the information revealed in the video.

Van Hanegan et al. used the video as a macrocontext for teaching special education students about strategies for solving measurement and distance problems. In this research, students were first given a pretest consisting of traditional word problems about distance and measurement. Half of these problems contained information that was relevant to the problem, and the other half contained both relevant and irrelevant information. Not surprisingly, children performed very poorly on both types of problems. Children were then divided into four different groups. Three of these groups received anchored instruction and the fourth group received traditional instruction in representing and solving distance and measurement word problems. The groups receiving the macrocontext differed in how explicitly they were instructed to use information in the video to formulate problems and in what kind of feedback they were provided about the representation of information and their solution to the problem.

After instruction, all children were given a posttest with word problems. Striking results were obtained again. Children who received anchored instruction significantly outperformed those who received traditional instruction on both distance and measurement problems, and they were less likely to be distracted by irrelevant information. This study provides further support for the conclusion that anchored instruction in problem solving provides powerful assistance to students with learning handicaps in transferring math problem-solving skills.

## IMPLICATIONS AND DISCUSSION

These and other studies have provided encouragement to the proponents of anchored instruction. These studies illustrate, however, but do not yet fully realize the possibilities afforded by this instructional innovation. For example, the macrocontexts described in this article were conceptually isolated from each other. Moreover, the linkages to other content areas and disciplines were not developed. A significant increase in instructional power would result from developing a series of videodiscs that depict situations in daily living presenting a wide range of real-world problems and that permit the exploration of databases that enable students to develop different disciplinary perspectives on the problems confronted by the people in these situations. With such a series and its associated databases, students would be able to view a single macrocontext that serves as a conceptual anchor for disciplines such as mathematics, science, social studies, and history.

The bottom line would be the creation of powerful instructional anchors that vividly and convincingly illustrate to children the real-world applicability of knowledge. This is one of the next advances to be realized in technology-assisted instruction. The research conducted thus far on anchored instruction lays down a firm foundation for this exciting next step.

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# Evaluation and Remediation of Cognitive-Communication Skills in Young People with Head Injuries

Patricia Johnson, Nancy Thomas-Stonell & Patty Young
Hugh MacMillan Rehabilitation Centre
350 Rumsey Rd., Toronto, Ontario
M4G-1R8, CANADA

## ABSTRACT

Cognitive-communication deficits are a major barrier to the successful reintegration of young people with head injuries. This paper describes an ongoing research study which is currently evaluating a newly developed computer-based cognitive-communication skills retraining program. This package consists of an "adventure-type" game and consists of two parts: a screening module and a remediation module. The program concentrates on five domains: attention; memory/word retrieval; organization; language comprehension and reasoning/problem solving.

## BACKGROUND

Many rehabilitation centres have implemented cognitive re-training groups aimed at the remediation of head-injured patients in the early stages of recovery. Jennet (1975), observed that tremendous efforts expended on intensive treatment in the early weeks after injury are often largely wasted by the failure to provide the means whereby the full potential for recovery can be achieved during the later stages. Research needs to focus on the development of adequate procedures for effecting cognitive change. (Finlayson, Alfona, & Sullivan, 1987).

This paper describes the work that is currently being carried out on a computer-based cognitive retraining program which focuses on the remediation of deficits found in the later stages of recovery: attention; memory; word retrieval; comprehension of abstract language; organization and reasoning/problem solving skills. This screening and remediation package utilizes a new approach to the rehabilitation of these skills by combining: speech output; voice recognition; data collection capabilities; cueing and help screens; animation; and multiple difficulty levels into an intrinsically motivating game format.

The objective of this study is to evaluate this highly innovative microcomputer-based program for remediating cognitive-communication skills in individuals who have sustained a head-injury.

## RESEARCH QUESTIONS

1. Is the screening module a reliable measure of skill levels in the domains of attention; comprehension; memory and word retrieval; organization; and reasoning/problem solving and thus a valid tool for measuring progress following the remediation modules?

2. Are the remediation modules an effective enhancement to traditional therapy for cognitive rehabilitation in the areas of attention; comprehension; memory and word retrieval; organization; and reasoning/problem solving?

## METHOD

Adolescents (age of 13-20 yrs) with closed head injuries who exhibit cognitive communication deficits are currently being evaluated. All subjects conform to the following:

- -exhibit higher level cognitive communication deficits
- -comprehension of basic syntax and linguistic concepts
- -intact expressive language skills at the sentence level
- -coma of 24 hours duration
- -initial Glasgow Coma Scale sore of greater than 8
- -score of 7 or 8 as defined by the Rancho Los Amigos Orientation Scale
- -absence of history of learning disabilities
- -3 months post onset

An A-A'-B within subject and between group design is being used. Three test sessions will be completed. Each session consists of the program screening module and the battery of standardized tests. The experimental (treatment) group is given the computer remediation modules three times per week for 8 weeks. The control group continues with their traditional therapy program.

A repeated measures of multivariate analysis of variance (A, A', B) (MANOVA) will determine the differences between test scores of the two groups from the three sessions. The MANOVA will analyze the effects of spontaneous recovery, practise and learning effects and traditional therapy. The dependent variables will consist of processing time, correct response, number of errors and number of trials. Also, non-parametric statistics will be used (Kruskal-Wallace).

## RESULTS

Preliminary evaluation, from a previous pilot study of the screening and remediation modules with three adolescents with closed head injuries and five non-head injured normal controls, indicated identical subject rankings from the screening module to those obtained from the standardized test battery. These results indicated that the program had preliminary face validity. As well, dramatic improvements in the performance of the two head-injured subjects who received remediation three times per week were observed.

In the current study, the screening module has been field tested with ten regular junior high and high school students in order to obtain baseline normative data for the program. Data is currently being collected and analyzed from the assessments of adolescents with closed head injuries, on both the screening and remediation modules.

## DISCUSSION

Improving cognitive-communication skills is of primary importance for the successful reintegration of young people with head injuries into educational and vocational settings. This cognitive retraining program promises to be an effective tool for remediating the cognitive-communication deficits exhibited by people with closed head injuries. Further work will be undertaken to assess validity and reliability of the program.

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## ADDRESS

The Hugh MacMillan Rehabilitation Centre
350 Rumsey Rd.
Toronto, Ontario
M4G-1R8
(416) 425-6220

# Applications of Artificial Intelligence to the Needs of Persons with Cognitive Impairments: The Companion Aid

Gregg C. Vanderheiden, Ph.D.
Cynthia J. Cress
Trace R&D Center
University of Wisconsin-Madison
Madison, WI

Abstract
A hypothetical device called a "Companion" is proposed as a way of applying advancing technologies to the needs of individuals with cognitive impairments. The device would use technologies most of which exist today, and would provide individuals with cognitive impairments with greater freedom and ability to live and move about independently. Communication, location, and computer technologies can be combined to provide assistance and safety without dominance over the user.

The purpose of this paper is to stimulate thought and discussion about the appropriate use of technology to enhance the abilities of indiv'duals with cognitive impairments, including the e hical issues in the use of artificial intelligence to assist individuals with cognitive impairments.

## Background

Technology can be used in a variety of ways to enhance the lives of individuals with cognitive impairments. In vocational settings, appropriate use of technology can increase the opportunity and accessibility of employment for people with disabilities (Cress, 1987; Anderson & Grasse, 1990). In therapy and education settings, technology can provide a context for practicing and improving selected cognitive skills (Iacono & Miller, 1990). In daily living activities, technology can provide functional assistance through prompting, problem-solving, memory, or enhancing aids (Vanderheiden, in press).

Specific assistive technologies that have been applied for persons with cognitive impairments have prompted or reminded users in specific, well-defined activities. For instance, simple mass-market watches or calendars can serve as cognitive prostheses to remind users of appointments or scheduled activities (Naugle et al., 1988; Henry et al., 1989). More complex computer-based strategies has been developed to prompt users in problem-solving for multi-step activities (Lancioni & Oliva, 1988; Cole & Dehdashti, 1990). Advances in technology such as speech recognition, artificial intelligence, and pocket-sized computers will increase the flexibility and power of these assistive technologies. The challenge remains, however, to best match the technology to the needs and abilities of the persons served, and to effectively facilitate cognitive processes or daily living skills.

## Statement of the Problem

A primary concern about the use of artificial intelligence in cognitive prostheses is the role that the technology plays in the user's life. Salomon et al. (1991) express this issue as the difference between effects *with* and *of* technology. The effects *with* technology address the changes in a person's performance while using intelligent technology, and the intellectual partnership that exists between user and device during operation. The effects *of* technology refer to the changes in cognitive or functional skills that occur in the user as a "cognitive residue" resulting from the use of technology.

Cognitive prostheses for persons with cognitive impairments can affect the results both *with* and *of* technology if the device functions as a companion rather than a director for activities. Companion technologies can not only extend or enhance an individual's cognitive abilities (effects *of* technology), but also augment the user's functional abilities during use (effects *with* technology). One example of companion technology incorporating artificial intelligence is a hypothetical device called the "Companion."

## Approach

### *The Companion: A Hypothetical Design*

The Companion is a small device approximately the size of a large wallet. It has four or five large buttons on it, which are brightly and distinctly colored and have symbols on them. One of the buttons stands for "Help." Two other buttons stand for "Yes" and "No." Another button is a request button. The Companion has voice output and speech recognition. It has an artificial intelligence system programmed within it which is specifically designed to facilitate problem-solving and crisis resolution. In addition, the Companion acts as a reminder and monitor system for the individual. The Companion has a built in loran system (a navigation system which determines latitude and longitude from remote radio signals), allowing it to keep track of its exact position. Finally, the Companion has a cellular communication system similar to a cellular telephone, allowing it to put the individual into instant contact with a crisis line in case of an emergency which cannot be easily handled by the Companion.

In daily use, the Companion would have certain regular activities would be programmed into the system. The Companion could wake the individual up in the morning, and then periodically ask the individual questions. These questions could help cue or prompt them through their morning routine, or operate as a check for individuals who do pretty well at progressing through their morning routines on their own. While of some benefit in routine operations, the Companion is really much more useful in helping to remember the breaks in routine. This would include days when the individual is not supposed to go someplace they normally go to (due to a special appointment, a holiday, etc.), as well as unusual things they must do or places they must go (doctor's appointments, etc.). Because the system always knows its physical location, it can automatically check the individual's progress and determine when the individual is not making suitable progress toward the programmed goal. For example, if the individual has a doctor's appointment, the Companion would remind them in time for them to get to the doctor's office. If the time for the appointment was drawing near and the individual had not made progress toward the doctor's office, the Companion would provide additional reminders to the individual, help them problem-solve the situation, or put them in contact with someone who could help them out.

As the day progressed, the individual would be able to request information or assistance from the Companion by pressing the "Request" button. The Companion would respond by talking to the individual and running through a list of functions to see what it was that the individual wanted. Because of the speech recognition capability of the Companion, the individual could also simply respond to the initial questions of the Companion by saying what it was that they wanted. Some of the functions that the Companion could provide include providing time of day, providing directions, checking appointments, providing telephone numbers, providing addresses, etc. Here's how the system might work for a young man, named Tim:

*On this particular day, Tim falls asleep on the bus on his way home from work, and rides past his normal stop. When he wakes up, he looks out the window, and finds himself in a totally strange part of town. He panics, gets off the bus, and begins walking aimlessly about the streets, becoming more alarmed as he goes. The Companion, recognizing that he is in an area that he has never been to before, and which is not on his agenda, beeps and asks him if he is okay, and if he knows where he was going. Using speech or the yes/no buttons, he answers the Companion's questions until the Companion is fairly certainly that he does or does not know where he is headed. If the Companion determines that he has a problem it would go into crisis/problem resolution mode, figure out what the problem was, and attempt to help him.*

*The Companion would start by asking questions to try to determine what type of problem existed. It would then run through a number of problem-solving strategies to try to help Tim to solve the problem himself. If this did not work, then Tim might be advised to seek help from those around him (depending upon the environment and situation). Finally, if the Companion was unable to help Tim to solve the problem himself or with the assistance of those around him, the Companion would use its wireless phone-like capability to contact a central, shared "Help" facility. This central facility would be manned 24 hours per day by individuals trained to provide assistance and problem-solving to people who have Companions. Since the central facility would have a basic file on each individual, as soon as the Companion contacted the central facility, background information on Tim would be instantly displayed on the operator's screen, along with any information that the Companion had been able to glean through its processes, including the individual's current location. At this point, Tim would be in direct voice and visual contoct with the operator, who would be able to talk to him in a fashion appropriate to his abilities, determine what the problem was, and help him to resolve the problem.*

*Tim does not have to wait until the Companion detects a problem if he is in trouble. Tim can signal directly that he has a problem by pushing the Help button. Tim could also skip the Companion's assisted self-resolution phase and go directly to the call to the central operator by pressing the Help button more than once.*

*Although Tim's Companion doesn't have this feature yet, a new model of the Companion has just come out on the market which also has a built-in reading capability. This new model of the Companion has a small window, like the viewfinder on a camera. Using the new model, if Tim saw some writing on a sign or paper that he could not read, he would be able to just look through the viewfinder, aim it at the text, and push a button. The Companion would take an electronic "picture" and then read the text aloud to Tim. This technique is also helpful in the way-finding strategies, because the Companion would also know what the sign said, and could provide some assistance, if it was a familiar type. For example, if Tim were near a bus stop, the bus numbers could be noted and used to help Tim get on the right bus. Similarly, when a bus approached, Tim could just aim the viewfinder at the word written on the bus and the Companion could confirm whether this was the proper bus for Tim to board. This reading capability would also have a certain therapeutic value to Tim, since it would display the picture of the text and then highlight the words one at a time as it spoke them. In this way, the Companion can facilitate Tim's learning and recognizing common or familiar printed words. It would also be possible for the Companion to transmit the digitized picture back to the central operator, in the event of an emergency or problem-solving. As a result, the operator would be able to "see" the problem more clearly, by simply asking Tim to "take pictures" of what the operator was interested in. Still or motion pictures could be sent, depending on the bandwidth of the system.*

**Implications**

The purpose of the Companion would be to allow individuals with mental retardation to live more independently. If the Companion could enable an individual to live safely in a less supervised or more independent fashion, the cost savings would very quickly cover the cost of the Companion. Even a moderate shift in independent living status can mean a savings of $10,000 or more per year. The cost of the Companion could be kept reasonable because of its widespread application with elderly individuals as well as with persons with cognitive impairments. It could help allow them to live safely outside of nursing homes for longer periods of time, and, in nursing homes, allow greater degrees of freedom while still allowing maintenance of necessary supervision.

Technologies such as the Companion are easily within our reach. The loran, cellular telephones, miniatute cameras, voice synthesizers, and microprocessors required for the Companion all exist and are in use today. Computer-based teaching of human activity is being developed and tested in pilot form (Jaros et al., 1991). The artificial intelligence and expert system routines which would be needed for the problem-solving systems in a Companion-class device exist, but not in the sophistication required for this application. However, steady progress is being made in these areas, and the computing power necessary to support these capabilities is advancing rapidly. In fact, computing power is advancing faster than any known technology. Computing power goes up by a factor of ten every four years. In addition, the cost for equivalent computing power going down by a factor of ten every five years.

In order to get some conception of these numbers, let's draw a parallel with the automotive industry. In 1965, you could buy a Cadillac for $10,000 that went 120 miles per hour. If automobiles were progressing at the same rate that computers are progressing, in 1990 you'd be able to buy either a $10,000 Cadillac that went the speed of light, or a Cadillac that went 120 miles per hour for 10 cents (Huray, 1990). (By the Year 2000, or you'd be able to buy ten 120-mile per hour cars for a penny.) As this analogy shows, computers and computing technologies are advancing at a rate that is inconceivable by ordinary technology standards and the potential of artificial intelligence will increase along with them.

The technology will therefore easily outstrip our ability to apply it effectively. What we do not have is knowledge of how to best utilize these technologies, or how to provide useful prompting to help a client figure out a problem rather than thinking for them. These are the critical missing components, and are necessary to transform an engineer's toy into a viable tool for persons with retardation.

**Discussion: Ethical Issues in the Use of Artificial Intelligence**

Artificial intelligence holds great potential for applications with people with cognitive impairments. However, its application must be carefully implemented to preserve their independence and freedom. If we were able to provide a person with mental retardation with an artificial brain which could think for them, would we have provided the person with new intelligence or would we have provided the artificial brain with a human body? Although artificial intelligence today is nowhere near the thinking or creative capacity of the human mind, we should be mindful that advances in this area are being made at a previously inconceivable rate.

We must, however, take great care in how we do this. If we attempt to make cognitive prostheses (an artificial brain for the person), we run the danger of thinking for the individual instead of facilitating his or her thinking and decision-making processes. For this reason, we should focus our attention on "companion" classes of assistive technologies. These technologies constitute an approach which involves the use of artificial intelligence to stand alongside a person with mental retardation or other cognitive impairment, accompany them through their lives, and provide assistance to them in the same manner as a human companion or guardian might. It should be programmed to facilitate the natural thinking and problem solving capabilities of the individual. In addition its companion or guardian function can allow increased freedom for the individual while still maintaining a link to assistance when necessary.

The ultimate goal is to create a tool that is under the user's control. In this way, assistive technology may provide advantages over the same assistance through other people. Human companions and guardians are susceptible to imposing their own points of view as well as their own wants and needs upon the people in their care. The "companion" device could be programmed to offer assistance or reminder services on any level deemed appropriate for the given individual. The individual would therefore be left to make their own decisions based upon the input from the "companion" or others in their environment.

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Gregg C. Vanderheiden, Ph.D.
Trace R&D Center
S-151 Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280

# APPLICATIONS OF TECHNOLOGY FOR PERSONS WITH SEVERE PHYSICAL AND DEVELOPMENTAL HANDICAPPING CONDITIONS

Paul J. McPhail
Applied Technology Laboratory
Southwestern Regional Centre
Blenheim, Ontario Canada N0P 1A0

## INTRODUCTION

The Applied Technology Laboratory at Southwestern Regional Centre opened in November, 1983 with the overriding goal to analyze, research, plan and develop or arrange for the development of a wide array of aids and devices to enable developmentally handicapped individuals more independence and self-support within Southwestern Regional Centre or within their home communities. The objective of the Applied Technology Laboratory is individual client-focused; practical applications of applied technology with timely implementation.

Having a population of just under six hundred individuals with somewhat unique needs served as a catalyst to explore, investigate, and experiment with the varied uses of technological equipment/aids to assist the person with developmental and physical handicapping conditions.

## METHODS

Nine years ago, the Applied Technology Laboratory was set up without a budget or staff in a small room in the basement. Today, the Applied Technology Laboratory has moved to the main floor, in the centre of the building and has sixty micro-computers, over six hundred pieces of software and many adaptive devices. One example of technology is that more than two hundred and fifty client are exposed to computer-aided- learning per week. 83% of these clients have been tested as profoundly or severely mentally retarded with physical handicapping conditions.

The Applied Technology Laboratory must conceptualize and put into operation assistive devices, aids and training methodologies for which there is no precedent or validation of effectiveness for developmentally handicapped individuals. Initiative and creativity are key requirements for the work the Applied Technology Laboratory does, as there are minimal aids, devices and research data available. The Applied Technology Laboratory must translate Ministry of Community and Social Services and the Ministry of Education directions and directives for the future applications of applied technology into practical itilization for candidates who are unable to advocate on their own behalf. The Applied Technology Laboratory must remain cognizant of current technological advances and developments in assistive devices, therapeutic program equipment, computer aided learning, communication aids environmental control devices and personal safety devices which could be adapted for use by this special client population.

Program - conceptualizing, planning, designing and implementing a service for developmentally handicapped individuals utilizing recent technological and computer electronics, as well as other mechancial and adaptive tools to promote self-sufficiency and independence. As a one-of-a-kind program in North America, the Applied Technology Laboratory is regularly sought after by organizations to enlighten them to potential applications for technology in a human service industry.

Applied Technology Laboratory's contact with major corporations, universities, agencies, associations, and government officials within Ontario, Canada and across North America provides a solid resource, data, and information base. This technological service network allows Southwestern Regional Centre and the Ministry of Community and Social Services to become a leader in the dynamic technological revolution in human service delivery systems

Applied Technology Laboratory is responsible for assisting in the recruitment/attracting and nurturing of volunteers to implement highly complex technological devices and systems. Volunteers have donated twelve thousand hours of service to the Applied Technology Laboratory (January 1984 to April 1992).

All Southwestern Regional Centre staff members, as well as interested individuals or groups from schools and community agencies, have the opportunity to come to the Laboratory to combine their talents, expertise, and problem-solving abilities regarding the uses of technical aids to assist those with developmentally handicapping conditions. This may take the form of individual or group designed projects, and/or collaborative efforts between those within and outside the facility such as applied research studies or student placements. This model will benefit the physical and mentally disabled, the elderly, persons with cerebral palsy, etc. These individuals with unique needs will have hope of living a more independent lifestyle as this technology is being designed to meet individual's needs.

Highly refined inter-personal skills are required when dealing with staff, peers, parents, volunteers, senior ministry and business officials, technical personnel, the media and numerous voluntary and resource groups throughout the province.

APPLIED TECHNOLOGY LABORATORY ACHIEVEMENTS AND ENDEAVOURS

Interface technology - a wide variety of single and multiple switches have been developed to provide access to a computer, electric wheelchair or adapted toy by virtually any part of the body with which a person has functional control.

Software development - a wide variety of software has been developed by volunteers to provide pre-requisite skills training for some commercially available or public domain software such as letter recognition as a pre-requisite to word processing. Audio and/or visual feedback are incorporated for reinforcement and to overcome sensory deficits.

Training models - Once the appropriate interface and software have been determined, training strategies with individuals need be formulated such as moblity training with an electric wheelchair or augmentataive communication training with the "Talking Blissapple".

Environmental Support Project -This concept is becoming a reality as the development of intelligent environments technology progresses. The primary objective is to provide maximized opportunity for skill development of individuals in a home-like environment which will foster optimum general independence and self-identity despite their physical limitations. The Environmental Support Project concept appears to have exciting possibilities in moving handicapped people toward an independent lifestyle.

Assessment Services - The objectives are: to provide assessment services that best determine individual needs and will facilitate the best treatment plan, day program placement or job placement, to provide a comprehensive, objective, clear and concise client profile to service providers such that the opportunity for success is maximized for the client, to provide consultation to service providers to maximize opportunities for client success.

These projects have the potential of having significant impact on the efficiency and effectiveness of service delivery to the adults with physical and developmental handicapping conditions at Southwestern Regional Centre, in the Tri Counties (Kent, Essex, Lambton), in Ontario and in Canada. The information gained would contribute to the field of habilitative training of people with physical and developmental handicapping conditions. The hardware, interface technology and software developed as the result of these projects would easily lend itself to applications with children in Special Education and other clinical populations such as the elderly.

When Southwestern Regional Centre first opened its doors in 1961, it was a home, school and hospital for over one thousand residents with physical and developmental handicaps. Over the years, many of the residents have moved into the community and the present residential enrollment is approximately 550 persons. Perhaps the service most identified with a facility such as ours is the provision of care, teaching, training and programmes for persons with physical and developmental handicaps who reside in our Centre. We offer these residents services and opportunities for personal growth.

The Applied Technology Laboratory has made an exceptional contribution to the physically and developmentally handicapped at Southwestern Regional Centre and special populations across Canada. The Applied Technology Laboratory has shown outstanding innovation in conceiving and developing new concepts, processes of widespread benefit to Canada.

Paul McPhail
Manager
APPLIED TECHNOLOGY LABORATORY
Southwestern Regional Centre
R. R. # 1,
BLENHEIM, Ontario Canada NOP 1A0
(519) 676-5431 Ext. 2264

22.6

# Issues and Trends for Special Education Technology in the 21st Century: First Year Findings

Elizabeth A. Lahm
COSMOS Corporation

## Abstract

A three year study, sponsored by the U.S. Department of Education, seeks to identify emerging issues and trends in technology for special education. By integrating three strands of information: 1) emerging issues and trends in technology, 2) emerging issues and trends in special education, and 3) factors affecting the interaction between technology and special education, the project analyzes their impact on special education technology for the early 21st century. The project has established a network of experts in science, technology, and special education and has implemented an electronic communications system for those experts to share their knowledge. This paper highlights some of the findings from the first year.

## Background

If H.G. Wells is right, and "the future is a race between technology and disaster," then we must begin encouraging schools to use technology. To ensure the race is won, and children are ready for the future, policy makers must plan for the emergence of new technologies and relate them to the changing needs of children. This is particularly important for children with disabilities. For them, technology holds the promise of a future with many more freedoms and an improving quality of life.

The U.S. Department of Education, Office of Special Education Programs, is planning for that emergence of new technologies. In a project designed to identify emerging issues and trends in technology for special education, OSEP will gain insight into the future and can plan for it. This three year project integrates three strands of information: 1) emerging issues and trends in technology, 2) emerging issues and trends in special education, and 3) factors affecting the interaction between technology and special education. The project has established a network of experts in science, technology, and special education and has implemented an electronic communications system for those experts to share their knowledge. The network includes the National School Boards Association (NSBA) as an active partner. The project is developing a series of papers, electronic events, individual investigations, and a satellite teleconference to identify and share information on what the world of special education might be like in the year 2010.

## Research Questions

The purpose of the project is two-fold. It investigates trends and issues in technology and special education, and experiments with the process of collecting that information. The specific research questions posed by the study are:

- What are the trends in technology and special education today, and how might these impact education for individuals with disabilities in the year 2010?
- How can this project best elicit information from its network of participants to arrive at a better picture of the year 2010?

## Method

The method for addressing the two research questions are interrelated. The project uses a network of experts in technology and special education as the primary information source. Three expert panels independently identify issues and trends in one of three areas: technology, special education instruction, and special education service delivery. An advisory board serves to guide these panels and assist in locating key information sources relevant to their work. Two project fellows assist with the synthesis of cutting edge research and development and the analysis of issues and trends across the three panels. A consortium of special education practitioners acts as a sounding board and reality check for the ideas generated by the panels.

The project participants only meet face-to-face once annually and use other communication mechanisms to dialogue year round. The project utilizes an electronic communication system to facilitate that dialogue. This system includes an electronic bulletin board established to network all project participants. The project conducts experiments with the bulletin board in conjunction with fax, phone, and mail capabilities to find which communication mode best achieves a specific communication goal. These experiments involve conducting planned events or structured interactions between project participants. They deliberately use communication protocols and facilitators to avoid haphazard and inefficient communication.

**Results**

Issues and Trends: The expert panel activities in the first year of the project identified the following issues and trends:

- The increasing demand being placed on teacher time and less time being available to integrate technology into the classroom;
- The uneven impact of technology resulting in the "haves" gaining even greater advantage than the "have-nots;"
- A resurgence of categories and segregated classes in some areas;
- Decreasing funds to support special education and an awareness of the need to embrace other community agencies;
- The digital storage of information on optical media;
- Multi-functionality in equipment or "extensible" equipment;
- The development of "firmware," technology comprising both hardware and software; and
- An increasing lack of policies governing the acquisition and implementation of technology in schools.

Communication Facilitation: After nine months of bulletin board operation and three planned events, the following hypotheses have been generated:

- Users of a new communication system must be nurtured to become a regular user audience. Nurturing may include contact by regular phone first to encourage system use;
- Better participation is achieved if commitment is obtained through scheduling electronic dialogue for a specific time;
- Frequency and value of new information available through the electronic system are important use variables;
- Electronic information is less luring when presented alone than when it is supplemented with video and audio stimulus materials;
- Bulletin board users prefer use their personal word processors to compose rather than composing directly on the system. This preference has implications for how the

system should be used; and

- Individuals in large institutions tend to only have access to large networks and have technical difficulty accessing outside networks.

**Discussion**

Dialoging about emerging trends in technology and special education can have important benefits. Such a dialogue can help educators and technologists to understand each other's worlds better, can increase awareness of potential matches and mismatches, and can lead to unanticipated benefits to students with disabilities. In short, raised consciousness about the interactions between potential technologies and potential needs can be but the first step in improving the uses of technology in special education. However, a distinctive analytic challenge is to promote the dialogue and to make projections about such emerging trends--forces that will change the educational world ten or even twenty years from now.

First, the dialogue must focus on emerging trends, not next year's schools or technologies. With school systems, such emerging trends must incorporate many unknown social, educational, and economic conditions. With technologies, emerging trends are different from existing or emerging technologies. An emerging trend is a topic about which no specific technology may yet have been developed. In the late 1940s, "automation" was an emerging trend about which much was written or speculated in the absence of specific automated devices. Similarly, the "disposable society," development of synthetic materials, and creation of intelligent machines all have been emerging trends at one time in the past. The challenge is to identify the emerging trends for the future.

Second, the dialogue must include persons familiar with both special education and technology. This means exchanging technical information across diverse fields. Therefore, different specialists must paradoxically be able to shed the communications barriers associated with their professional training and practices and, at the same time, exchange information about their own worlds.

Third, the dialogue must be congruent with known conditions and existing trends. In other words, to dialogue productively about emerging trends is to control or at least be sensitive to irrational urges toward fantasy. Thus, history cannot be reversed, and certain fundamental norms in American society will not change radically.

This project is currently trying to promote such dialogue and to meet these three analytic challenges. The project facilitates information exchange through face-to-face as well as electronic modes. Commissioned papers are produced by experts, to permit the more thoughtful review of new ideas. As an adjunct, concomitant review of existing research and educational conditions is conducted, to assure that the dialogue takes advantage of the latest information.

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Elizabeth A. Lahm
COSMOS Corporation
1735 Eye Street, N.W., Suite 613
Washington, D.C. 20006

# Going to Market: Attempts to transfer a custom design into the commercial market

**Susanne H. Shealey M.S. OTR** Communication Enhancement Center, Children's Hospital, Boston, MA
**Charlyene Besedick** Design Engineer, Prentke Romich Company, Wooster, OH
**Colin Twitchell, B.A.** Adaptive Equipment Designer, Institute on Applied Technology, Boston, MA

## Abstract

Selection of the most appropriate mount for a portable augmentative and alternative (AAC) communication device can significantly influence one's success and efficiency of communication using an AAC device.
This paper describes a process used to transfer an Adaptive Equipment Designer's product design, namely a laptray mount for portable AAC devices, into the commercial marketplace. This AAC device mount did not make it to market. By sharing our firsthand attempt at a "technology transfer effort" we hope to retrace our steps, elucidate possible pitfalls and provide retrospective insights on ways in which the process might have been improved.
Ultimately we hope to contribute to the growing body of knowledge in the area of technology transfer.

## Background

Many factors contribute to one's functional abilities to communicate using an AAC device. One important factor relates to provisions for mounting the AAC device mount so that it is consistent with each user's overall needs and requirements. Within recent years the commercial marketplace has witnessed the appearance of many portable AAC devices for persons who are non-speaking. Unfortunately there hasn't been a concomitant development of improved mounting options for these devices. This paper focuses on our collaborative attempts to transfer a custom design for an AAC device mount into commercial manufacturing and distribution.

**Designer's perspective:** Considerations influencing decision to pursue the transfer of this AAC device mount into the commercial market included as follows:
- within the clinical setting prototypes of this AAC device mount were positively received by many persons using AAC devices.
- it was strongly felt that provisions to facilitate one's physical and visual access to AAC devices would result in easier, more efficient communication.

Designer was looking for a manufacturing group which
- would regard this AAC device mount as a positive addition to their product line.
- was a leading, respected manufacturer of AAC devices
- had a well-established distribution network

**Manufacturer's perspective:** Accepting a product to manufacture involves many issues. In order to properly address these, we need to review the prototype hand on and the drawing and other documentation. (Since no engineering drawing existed for this project, their creation became part of the task.) Does it fit our mission and with our existing product lines? Is it compatible with our distributior channels? What will be proprietrary? Will we have exclusive rights? After the prototype review, we asked, Do our Research and Development and Service Departments support it? Continuing on with a business analysis we considered- Will we need new skills? Is any investment needed? What is the cost to manufacture it and what is the impact on our present manufacturing? Is demand strong enough to justify entering the market?

## Design Rationale

Even though the focus is on a technology transfer process it is important to have some background on the actual custom design, a laptray mount for portable AAC devices.
Within the clinical setting this laptray mount met with much interest and acceptance by many AAC device users. This mount was unique in that its design addressed the interaction between the person and their AAC device, incorporating the following features:
- recessed casing allowed the keyboard to be positioned flush with the laptray surface to protect the device but also .
- recessed device was surrounded by additional laptray surface which allowed for greater forearm support and also surface for other materials.
- AAC device could be angled independent of the horizontal laptray surface.
- flexible lid could be used for device protection either protecting the keyboard and/or providing accessible surface for other activities, such as pageturning.

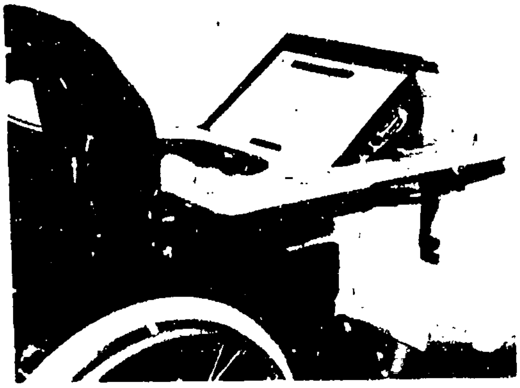

**Fig. 1. Functional SLIDE ON prototype mount**

## Going to Market:

### Method/Approach

Two different AAC device mounts, the SLIDE ON and the HANDS ON, were to be explored. Initial efforts focused on the SLIDE ON version as the manufacturer felt this mount had a potentially larger market and also that it would be easier to manufacture.

This project was officially launched in early February, 1991 when the focus, scope and timelines were defined as well as the roles and responsibilities of both parties. Key points which were mutually agreed upon included:

- Manufacturer would utilize its resources to manufacture, market and support this laptray mount.
- Manufacturer was to create drawings which are necessary for producing the laptray.
- Selling price was to be under $1,000.00 per laptray mount.
- The mid October, 1991 Closing the Gap Conference in Minneapolis was targeted as the date for the introduction of this new mount. Also product information and pricing were to be available.
- Designer would be primarily responsible for finalizing functional prototype, and providing product information to the manufacturer regarding potential users and applications support.
- Project phases and timelines were outlined as seen below.

#### Phases of the Collaboration

**Phase I**: Assessment of function and design of AAC device mounts. Primary responsibility of designer with assistance from manufacturer

Both parties worked closely and communicated regularly to further define features of functional prototype. In mid-May, 1991 functional prototype of the SLIDE ON mount, including its angle adjustable feature was shipped to manufacturer. Simultaneously the following areas were being pursued:

- manufacturer's legal counsel drafted an initial licensing agreement.
- designer requested some upfront monies to support continued involvement
- ongoing communication between designer and manufacturer regarding product materials, costs, tooling, machine drawings and other manufacturing related issues.

**Phase II:** Transfer of Product from Designer to Manufacturer

Primary responsibility of manufacturer with assistance from designer.

On June 18, 1991 manufacturer generated specific project timelines.

A completed functional prototype of the SLIDE ON mount was shipped to manufacturer in late June, 1991. Included were the timelines for the manufacture of preproduction prototypes which were required determine final costing and finetuning of manufacturing and production procedures. Also these prototypes were scheduled to be shown at Closing the Gap Conference in Minneapolis in mid-October, 1991.

**Phase III**: Manufacturer's Development of Marketing and Applications Support Materials

Primary responsibility of manufacturer with assistance from designer.

**Phase IV**: Customization of AAC Device Mounts

Primary responsibility of manufacturer with assistance from designer.

### Results

#### Designers perspective:

Up until early October, 1991 this collaboration seemed to be progressing smoothly with timelines being met as initially outlined. However, as the SLIDE ON preproduction prototypes were nearing completion the manufacturer realized that their associated inhouse manufacturing costs were considerably higher than initially projected. At this time the manufacturer reported a revised selling price for the laptray mount which was more than twice the initial estimate. Needless to say, this development altered plans for the Closing the Gap Conference. Rather than announcing the SLIDE ON mount as a new product in Minneapolis, the manufacturer decided instead to conduct a marketing survey. By investigating other manufacturing alternatives based on significantly higher sales quotas, the manufacturer was able to reduce the estimated selling price, but it was still 30% higher than the initial estimate.

Only one week prior to the Closing the Gap Conference did the manufacture's marketing department request mount information, specifically for purposes of a marketing survey. The results of this marketing survey were discouraging with the majority of respondents stating that any price exceeding $1200.00 was unacceptable. Additionally many felt that the SLIDE ON mount lacked sufficient flexibility to satisfy a wide range of individual needs. As a last attempt to rescue the faltering AAC device mount collaboration both parties agreed to provide the manufacturer's network with a descriptive videotape and feedback form on the second mount, the HANDS ON. Unfortunately this feedback wasn't sufficiently encouraging to warrant continuation of this joint effort

By this time in mid-December both parties had made substantial investments of both staff and money. In light of the relatively high price and limited field support it became quite obvious that neither of these AAC device mounts were going to make it into the commercial market.

The designer felt that the following factors might have played a role in the demise of this "technology transfer" collaboration:

- **Timing:** The designer was proceeding on the basis of the manufacturer's current AAC device mounting options. We had no knowledge that simultaneous to this collaboration that the manufacturer had been negotiating with another AAC mount designer. If this information had been known upfront it might have altered the course of action.

## Going to Market:

This situation would seem to point out the need for collaborating parties to be honest and upfront with each other so that valuable time and money are not wasted.

• **Communication and Coordination**: Despite recommendations to involve marketing and other departments early on and throughout the course of this project it appears that these areas weren't adequately addressed.
It is very important that provisions exist for excellent designer/manufactuer communication as well as communication between all involved staff.

• **Project Coordinators**: Given that a clinician with AAC experience served as the designer's Project Coordinator and a design engineer served in a simillar capacity for the manufacturer, this difference in backgrounds and perspective may have added considerably to less than effective communication.

### Manufacturers' perspective:

There are several reasons why this project was not successful. From the beginning, the manufacturer treated it as a Research and Development project instead of a business venture. This was due partly to the history of the relationship between principals representing the designer and manufacturer which resulted in an informal working arrangement. For this reason some important initial steps were not completed. Foremost in these steps were proper market analysis and professional feedback

Another factor was that we were not experienced in the type of manufacturing techniques which were needed to make the laptrays. This led to significantly underestimating the manufacturing cost. We then pursued alternate manufacturing approaches, but were still unable to bring the product to market for the initial estimate.

For a product such as this laptray mount, the manufacturing cost is largely dependent on the amount of time required to build it, especially if it is produced in low volume For this project, the actual manufacturing time was half of the prototyping time. In the future we will use this as a tentative rule of thumb in estimating product costs.

This project has shown us how important it is to have policies and procedures in place for the development of products that come to us from external sources. This experience has helped us to better define our own system for handling new projects in the future.

During this collaboration process we were approached by another developer who had designed a wheelchair mounting system. Substantially different from this AAC device mount, this second system had already been available and was viewed as a totally separate product. As such, information regarding its development status would be considered confidential and proprietary. We believe that we were totally candid regarding all issues that were relevant to this project.

## Discussion

Even though nc new AAC device mounts succeeded in making it to the commercial market both parties agree that a lot was learned from this project. Out of our joint willingness to embark upon this venture we have the following recommendations for future technology transfer collaborations:

• Since the technology transfer process seems to be largely determined by manufacturer- driven considerations it would seem beneficial for manufacturers to create a Technology Transfer Review committee.
This group would review all outside designs and determine whether the transfer process takes place or not.

• Establishment of effective ongoing lines of communication so that both parties have an indepth understanding of each others needs and requirements. Designers and manufacturers should define specific areas of knowledge and questions to be asked.

• Develop solid business, legal and financial arrangements.

• Completion of comprehensive market survey .

• Manufacturer needs to know time involved in fabricating design prototype

•Develop specific guidelines for roles and responsibilities of all staff.

**Acknowledgements:** We wish to thank all those individuals who assisted throughout this collaborative effort.

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Susanne H. Shealey, M.S. OTR
Communication Enhancement Center
Fegan Plaza
Children's Hospital
300 Longwood Avenue
Boston, MA. 02115
(617) 735-6486

23.2

# THERMOSTAT DESIGN: THE IMPORTANCE OF APPEARANCE


Sandra H. Denno
University of Wisconsin-Stout
Brian A. Isle, James Odom, & Stephen V. Metz
Honeywell, Inc., Minneapolis, Minnesota



## ABSTRACT

This research examines the preferences of individuals with disabilities and the elderly to one of four thermostat designs. The results indicate that no single style of control will be best for all people and a control that can be used in different ways according to the abilities of the user can benefit most people. The results also show that appearance can be more important than ease of use and that most important is appearance that is similar to equipment used by others.


## INTRODUCTION

This research is one part of an on-going project to write product design guidelines that will make common household appliances easier to use by the elderly and people with disabilities. Considerable research has been performed applying human factors in the design of controls for ninety percent of the population (McCormick, 1982). Guidelines are available with general information for design of consumer products to increase their accessibility to people who are aging or have disabilities (Vanderheiden, 1991). There is very little information available concerning the abilities of people with various disabling conditions as they relate to product design. Kanis (1988) observed people with arthritis and muscular dystrophy operate their own products in their own home and quantified their capabilities to turn knobs. Metz (1990) reported the abilities of people with arthritis to turn knobs of various sizes, shapes and surface textures.

The purpose of this research is to determine which of four types of thermostat designs would be preferred by people with reduced hand, wrist, or finger strength or dexterity, tremors, and/or reduced eyesight due to aging or disability. Through observation and participant response it was hoped that insight would be gained in the direction of universal design for thermostats and other household controls.

## METHOD

### Participants

One hundred nineteen people participated. Each participant had one of the following conditions resulting in decreased hand function: neuromuscular disorders including multiple sclerosis and cerebral palsy (n=48); arthritis and carpal tunnel (n=23); spinal cord injury (SCI) (n=14); and elderly (average age 68.9) with no known disability of the hand or wrist (n=34).

### Apparatus

Four thermostat styles were evaluated. One thermostat is round with a diameter of 3.7 inches. The dial has a diameter of 2.3 inches with a serrated grasping surface 0.25 inches high. There are four numbers above the dial, a 5, 6, 7, and 8, corresponding to 50, 60, 70, and 80 degrees and a large arrow on the edge of the dial. These numbers are 0.34 inches high and slightly raised and can be felt by someone with normal sensation in the fingers. There are also raised hash marks every two degrees. This is referred to as the "small dial" thermostat (Figure 1).

The "large dial" thermostat is an adaptation of the small dial model. It has a large clear plastic dial completely covering the front and sides of the thermostat base. The dial has a diameter of 4 inches and a ridged grasping surface 0.7 inches high. The large raised numbers are clearly visible but are covered by the dial and cannot be felt (Figure 2).

The third thermostat evaluated, the "handle", is also a modification of the small dial thermostat. It has a 4 inch long plastic handle attached to the dial at the center of the thermostat and hanging below the base. The handle is 0.1 inches thick and 0.8 inches wide at the tip. The thermostat is adjusted by moving the handle to the right or left (Figure 3).

The last thermostat considered is referred to as the "magnifier". This consists of a common round thermostat with a dial diameter of 1.75 inches and a textured rim less than 0.1 inches high. A plastic magnifier was attached over the face of the thermostat two inches away from the dial. This device is commercially available and was designed as an adaptive device for people with impaired vision. This thermostat is adjusted by reaching under the magnifier and turning the dial.

The four thermostats were attached in a row on a board mounted on an easel. The height of the board could be adjusted so the thermostats were either 42 or 60 inches from the ground.

### Procedure

Each volunteer was presented the board of thermostats and given a description and a demonstration of how each style of thermostat operated. The participants were then asked to try each thermostat and indicate which they preferred and why. Participants who had visual or motor

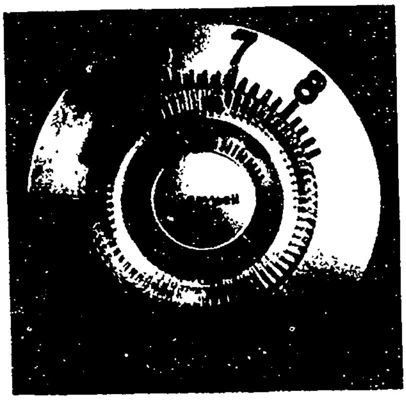


Figure 1: Small Dial Thermostat

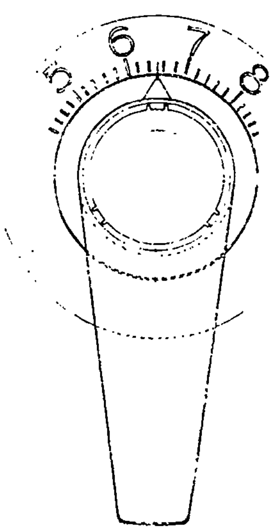


Figure 2: Handle Thermostat

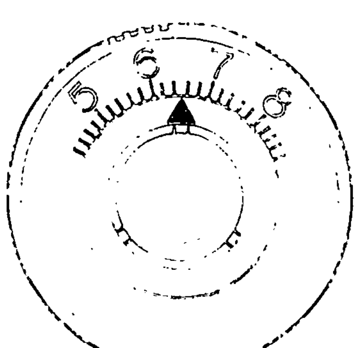


Figure 3: Large Dial Thermostat.

difficulties were asked to set the thermostat at a specific temperature. Participants who questioned what was meant by "preferred" were asked to indicate which thermostat they would purchase if given only these four choices.

Participants who walk all of the time evaluated the thermostats at 60 inches from the ground. Volunteers who use a mobility device all of the time evaluated the thermostats at both 60 inches from the ground and also at 42 inches from the ground. Participants who use a wheelchair or three wheeler to get from one place to another but often stand to perform tasks evaluated the thermostats at 42 inches while seated and at 60 inches while standing.

## RESULTS

Table 1 shows the percent of participants classified by disability, that prefer each thermostat type.

Table 1: User Preferences

| A. Style/Disability: | Neuro-muscular (%) | SCI(%) |
|---|---|---|
| Large dial | 41 | 75 |
| Handle | 45 | 25 |
| Small dial | 14 | 0 |
| Magnifier | 0 | 0 |

| B. Style/Disability: | Neuro-muscular (%) | SCI(%) |
|---|---|---|
| Large dial | 25 | 45 |
| Handle | 64 | 55 |
| Small dial | 11 | 9 |
| Magnifier | 0 | 0 |

| C. Style/Disability: | Neuro-muscular (%) | Joint(%) | Elderly(%) |
|---|---|---|---|
| Large dial | 62 | 54 | 57 |
| Handle | 23 | 23 | 24 |
| Small dial | 15 | 19 | 16 |
| Magnifier | 0 | 4 | 3 |

Table 1. Percent preferring each thermostat style (A) height=42 inches, participant seated (n=54); (B) h=60 inches, seated (n=39); (C) h=60 inches standing, (n=69). Neuromuscular includes multiple sclerosis, cerebral palsy, and other neuromuscular disabilities and joint includes data from participants with carpal tunnel and arthritis affecting the hands.

Of all participants tested in any position, the large dial was preferred in 49% of the responses, the handle in 36%, the small dial model in 14% and the magnifier in 1%.

## DISCUSSION

The magnifier was the least acceptable thermostat style. None of the participants that evaluated the thermostats at 60 inches while seated could see or manipulate the magnifier. Most volunteers that used a mobility device could not maneuver into position to see the numbers through the magnifier even when the thermostats were mounted at 42 inches and many were not able to reach under the magnifier to manipulate the dial. Over 85% of the comments regarding this thermostat were negative. This is an example of an adaptive device that is unattractive and of limited applicability.

The small dial generated the least number of comments. Some participants commented on the difficulty of operation but only one volunteer indicated that it was the most attractive.

The handle was identified by a number of participants as the easiest to use but many indicated that it "is unsightly" and looks "disabled". One participant with arthritis identified the handle as the most comfortable for her hand while a volunteer with multiple sclerosis found it painful to use.

Overall, the large dial was preferred over the other three styles, however, two volunteers with arthritis found the large dial difficult to handle. Although many comments reflected ease of use and satisfaction with the appearance, one participant indicated that she would not be interested in having one now but may be interested "when I'm older and need it".

An analysis of the researchers observations and comments made by the participants indicates that although the handle seems to be easier or at least as easy to operate as the large dial, it was considered less acceptable or completely unacceptable because of its appearance. The concern about appearance over function was even more obvious in a comparison of the small and large dial types. The small dial required greater force to grasp and turn and a more precise grip and most participants were observed to operate the large dial with greater ease but the small dial was listed as preferred in 13 percent of the trials Some of the subjects preferred it because "I don't like things too easy", and "I'm used to one like it".

Reaction to the large numbers was positive with volunteers with and those without visual impairment. Several participants with good vision thought the large numbers would be helpful to them in low light situations

The implication in universal design is to develop products with controls that can be operated in various ways according to the abilities of the user and that don't look adapted As more accessible but attractive designs for controls are made available, they will no longer look out of place or adapted and will become more widely accepted

## ACKNOWLEDGEMENT

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Sandra H. Denno
Center for Rehabilitation Technology
University of Wisconsin-Stout
Menomonie, WI 54751

# THE DESIGN PROCESS IN THE DEVELOPMENT OF ASSISTIVE DEVICES

Gunnar Fagerberg[1], Kerstin Sandberg[2], Maria Benktzon[3]
[1]Swedish Handicap Institute and INROADS, London, Canada
[2]Swedish Handicap Institute
[3]Ergonomi Design Gruppen, Stockholm, Sweden

## ABSTRACT

The paper describes the design process from the needs analysis to the finished product. The importance of thorough preliminary studies and the involvement of industrial designers is stressed.

## BACKGROUND

The development of assistive devices in Sweden is strongly linked to a socially based system (1). Funding is available for the innovative and development process. Small and middle-sized manufacturers can receive support to cover some of their costs during the critical period when products go into production (2). There are well defined purchasers within a limited sector. The devices are free of charge for the consumer.

Together, these factors have been very important for the present "social design process" in Sweden. As a consequence, there has been an opportunity during a long time to build a knowledge of methodology that we consider necessary for a successful development result. Product development has now reached such a level that there is no room for sudden ideas that are quickly pushed through to a finished product.

## THE DESIGN PROCESS

The Swedish Handicap Institute is the central government agency for matters relating to assistive technology. One of the main functions of the institute is to carry out **needs analyses** describing how persons with different disabilities live their lives in their own environment with or without devices.

The needs analyses are used both as a means to initiate the development of new devices (or the improvement of existing devices) and for providing information about the problems and possibilities of the users of devices. However, the needs analyses are not always sufficiently detailed to provide a complete picture of a specific development need.

Therefore, **pre-studies** may need to be performed before the actual development work can begin. In the pre-studies, existing devices and other "pilot material" are tested in real situations in order to stimulate a richer discussion with the consumers. The pre-studies as well as the development work are carried out by the designers (product developers) in order not to lose any knowledge. The studies often produce functional analyses and other elements that build a valuable knowledge base for other projects.

Next, the real **development work** starts. It can be characterized as an experimental ergonomic work with different test models (function models) in direct cooperation with the users. By testing the models, knowledge is built about the movement patterns and force resources of the users as well as an understanding of the users' physical and mental potential for the intended activity.

The following **analysis period** determines if tests with new models have to be performed. Occasionally, the subjects must test several function models before an acceptable design is reached.

Our experience shows that a very good knowledge base and a thoroughly developed methodology are necessary to successfully carry out these development projects. It is a very systematic process which does not permit any shortcuts. There are many "inventors" who have failed to transfer an idea for a "simple" device into a satisfactorily designed product because they did not master the methods of user studies or possess the full knowledge of the characteristics and the functional abilities of the final users.

When the device has been given its final design, that is when function and appearance satisfy the demands of the users, a hand-made **proposed model** is presented to the intended manufacturer/marketer. A **prototype** is made, based on which the product is adapted for production.

## PROBLEM FACTORS

The design process can be long and difficult, especially when developing devices for persons with multiple disabilities or for severely disabled persons. Public and private funding support is essential for the development of good small devices for persons with mobility impairments. It is precisely for this kind of projects that it is necessary to use funds without repayment or profit requirements for pre-studies and development work.

Companies who take on the marketing of odd devices in small series can not be expected to carry the cost of a long development process. It would in turn end up in unacceptably expensive devices that would not reach the users.

The purchasers, whether they be the health care system or the consumers themselves, cannot afford to have the development cost entirely included in the price of the individual products.

However, user studies, needs analyses and pre-studies, are sometimes difficult to fund from regular sources of research and development funding.

User studies should be the basis of all development projects. This is true also for standard consumer products, machinery and innovations in communication technology. Carelessly and ignorantly designed everyday products require more than a reasonable time and effort when used by a person who already has limited resources. Some persons with disabilities may be totally excluded from using such products (3,4).

To improve the possibilities for good accessibility, generally in the common environment and specifically in adapting housing, worksites as well as the design of everyday products, a compilation of facts on the ergonomic requirements of persons with disabilites is needed. A handbook in "disability ergonomics" as a complement to other ergonomic literature can be seen as a project of great importance both from a human and a social-economical point of view.

## THE FENIX CANE

As an example, we will briefly describe the development of the Fenix cane. Needs analyses had shown that many persons experienced the use of existing supporting canes as painful or uncomfortable. Some users wrapped their cane handles with a piece of cloth to make them a little more comfortable.

Initial studies showed that different types of disabilities had different requirements. The development work had to focus upon one group. In this case, persons with arthritis were selected.

In designing a cane, the goal is to reduce the load on a painful hip, knee or foot joint. However, this often causes additional problems of the upper limbs such as increased pain or deformity.

Before starting the development work, interviews and practical tests with users were conducted. Hand positions and walking patterns were studied and registered. Poor contact betweeen the palm and the supporting areas of the handle was characteristic for most existing canes when used by arthritics. Thus, the load bearing areas were reduced and the pressure increased. Notably, the load was often located to the thumb/forefinger area which explains the considerable pain that was reported in the thumb and thumb crease. This was verified by prints made using paint on the cane handle. They showed little support on the ulnar side of the palm. Existing canes also often separated the fingers and forced them apart in a painful manner. It is desirable that the fingers can be flexed together.

Experiments with adjustable angles of existing cane handles were also made. The majority of the subjects wanted to change the angle of the grip in order to increase the load bearing area. As the load bearing areas on existing canes are more or less horizontal they cannot be utilized by persons with stiff wrists.

Based upon criteria from this investigation, proposals for new design solutions were made. Several models were made and tested. A new anatomical handle was designed which increased considerably the contact area between the hand and the handle, thus providing better support. Seemingly small differences can be of vital importance for function, safety and comfort, something that can only be discovered through tests with users. Each step is recorded to provide evidence that one solution is better than another.

The final design of the new cane is characterized by:
-Larger load-bearing areas for the hand, without the usual consequence of the thumb being pushed out of place.
-The tube is placed at the back of the handle which allows the fingers to be flexed together.
-Good friction and a soft grip surface enhance the comfort.
-The angle of the handle is adjustable to each individual using a ball-and-socket joint.

The cane was made as light-weight as possible, an important consideration for a person suffering from pain in the shoulder joint. A weight difference of as little as 50-100 g may be important to the user. The tube is cut off to the right length for each individual, instead of having an adjustable length with a double tube. The cane is also provided with an elastic wrist strap.

The example shows the general truth that many apparently simple devices need a thorough design process in order to achieve a satisfactory result.

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Fenix is a trade mark of ETAC Sweden and ETAC USA.

Gunnar Fagerberg
INROADS
The University of Western Ontario
Faculty of Applied Health Sciences
Elborn College
London, Ontario
CANADA N6G 1H1

# The Ontario-based Rehabilitation Technology Research and Development Consortium

Morris (Mickey) Milner
The Hugh MacMillan Rehabilitation Centre
Toronto, Ontario CANADA

## Abstract

This paper describes the nature of a newly created Rehabilitation Technology Research and Development Consortium designed to link universities, clinics, consumers, manufacturers and marketers to address the rehabilitation technology needs of consumers, while building a stronger research base to effectively transfer relevant technology to the industrial sector. The Consortium is to address problems relating to seating, mobility, prosthetics, orthotics, hearing, communication, vision and respiration through teams in each of these areas. It includes also a Psychosocial Evaluation Team (to facilitate meaningful ways of consumer participation and measures of issues such as quality of life) and a Technology Transfer Unit.

## Background

Rehabilitation engineering efforts are being directed largely at providing opportunities for individuals with disabilities to achieve greater independence and participation in society, obtain employment and enjoy leisure time. Appropriate means are needed to ensure that technological developments are most fruitfully made available to those who can benefit from them.

The Ontario Ministry of Health supports the provision of assistive devices by providing 75% of the cost of a wide range of devices and currently expends about $100-million per year. The Ministry has recently funded a Rehabilitation Technology Research and Development Consortium with a ten year commitment at the level of $1,5-million per year, which the Consortium must augment by $750,000 per year. This must be done by matching funds acquired through grant applications made to other agencies and resources which the Consortium partners themselves contribute. The Consortium is designed to link universities, clinics, consumers, manufacturers and marketers to address the rehabilitation technology needs of consumers, while building a stronger research base to effectively transfer relevant technology to the industrial sector. Its current partnerships involve a wide spectrum of individual consumers, consumer organizations, several universities and educational institutions and their related clinical facilities including The Ontario Institute for Studies in Education, Ottawa University, Queen's University, University of Toronto, University of Western Ontario and Waterloo University. The Consortium is to address problems relating to seating, mobility, prosthetics, orthotics, hearing, communication, vision and respiration through teams in each of these areas. It includes also a Psychosocial Evaluation Team to facilitate meaningful ways of consumer participation and measures of issues such as quality of life, and a Technology Transfer Unit. A Management Committee comprised of Team Leaders, each with at least a 30% time commitment to the Consortium, is to administer the operation. Team Leaders in the various areas are expected to ensure that team commitments are met. The Consortium, through its Director, reports to an Advisory Board involving high profile representatives from consumers, the scientific community, industry, and service agencies.

## Thematic Attributes

The essential purpose of the Consortium is to enhance the quality of the lives of persons with disabilities, their families and communities. For its impact to be felt, Consortium endeavours must relate to outcomes in terms of one or more of the following thematic attributes:

EMPOWERMENT of the person; assurance of the DIGNITY of the person; enhancing the INDEPENDENCE of the person; assuring SAFETY for the person and the community; assuring RELIABILITY of developed devices and systems; and, enhancing the SOCIALIZATION of the person.

## Seating

Two projects are involved initially:

1] Further development and clinical evaluation of a modular adjustable seating system.
2] Development of restraint systems for transporting persons with physical disabilities in motor vehicles.

## Mobility

The research focus for this area is: Mobility, agility and device control in the home and community.

## Prosthetics and Orthotics

This is a team combining efforts in the two areas. Four projects are involved:

1] Functional neuromuscular stimulation using injectable stimulators.
2] Modular ankle-foot orthoses for children.
3] Programmable autocalibrating myoelectric control system.
4] Development of new energy recovery below-knee and above-knee prostheses.

## Hearing

Two projects are of concern:

1] Electroacoustic evaluation of hearing devices.
2] New systems for fitting hearing devices.

## Communication

This team's projects relate to the development of multi-modal augmentative communication technology with emphasis on low resolution headpointing and face-to-face expression of non-verbal aspects of communication.

## Vision

The two projects in this area are:

1] Spectacle-borne autofocus low vision telescope research and development.
2] An electronic reading and reference package.

### Respiration

This research focuses on the evaluation of mechanical ventilatory support devices with a view to better understanding their effectiveness, safety, reliability and application with a view to furthering their design and development. Two specific projects are:

1] Information system regarding the impact of home ventilation.
2] Application of innovative non-invasive ventilator technology.

### Psychosocial Evaluation Team (PSET)

Research programs are to be pursued to aid the Consortium in assuring effective consumer involvement. In addition to promoting and studying mechanisms for such involvement using techniques such as focus groups, epidemiological and survey research, and solicitation of input from formal consumer groups, a project concerning the establishment of a telecommunications network is proposed. A second major project is to investigate the potential of current quality of life instruments and their appropriateness for use by the Consortium's teams.

### Technology Transfer Unit

This unit is designed to interact with all of the research teams,including PSET,and the industrial/commercial sector with a view to assuring that developed assistive devices and technological systems can be made available as quickly as possible for the benefit of consumers. The unit will undertake technology assessments; facilitate prototype development, fabrication and testing; create product literature, including manuals and relevant technical and user information; and facilitate the acquisition of patents, copyrights and the issuance of licences,and expedite legal processes.

### Evaluation

The Consortium will review its progress annually and report on this along with each subsequent year's plans to the Advisory Board. Its experiences will be shared as widely as possible with a view to expanding upon its possible successes in other locales.

### Conclusion

It is hoped that the model described in this paper will be of value to others who are concerned with the spectrum of effort required in assuring that rehabilitative technologies reach those people who need them as expeditiously as possible.

Morris (Mickey) Milner
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road Toronto, Ontario
CANADA M4G 1R8

# A Coherent Approach for the design and development of assistive devices for elderly and disabled consumers.

Robert Brown ,Brunel Institute for Bioengineering.Brunel University.Uxbridge Campus
David K Wright.Brunel University.,Runnymede Campus.Egham.West London.U.K.

We report on the development of a system for the design ,development , prototyping , evaluation and manufacture of devices for a wide range of elderly and disabled consumers at the Brunel Institute for Bioengineering.

## Introduction.

The Institute ,set up in 1983 is a self financing organisation with expertise in developing design concepts at the interface between biology, engineering and medicine.A multidisciplinary team approach to problem solving allows it to adopt a lively and innovative approach to design for rehabilitation.It is based on the university campus ,and,has collaborations with departments within the University although its finance originates in the main from charitable organisations and commercial research contracts.

## Consumer Products.

In the institute'sRehabilitation Engineering unit the products under development are aptly described as "Tools for Living"[1] rather than aids for the disabled ,there is an implication that disabled people simply lack the appropriate tools.In addition to disabled people suffering from diseases such as Motor Neurone disease ,Cerebral Palsy,Multiple Sclerosis we are concerned with the development of tools for elderly clients.Here we are particularly concerned with products which enhance the quality of life of this segment of the population increasing independence through the application of technology.

Many of our past products have been developed in response to a specific user need identified through consultation with clinicians and users ,an application is then made for funding research and development by submitting a proposal to an appropriate medical or private charity.We are developing a more generic approach to problems which will allow a solution to be used in a number of different situations.This is not to be taken to be the same approach as that which adapts a solution from one area to give a solution for a new client group.The design from concept stage takes account of likely applications and incorporates this flexibility and adaptability into the product.

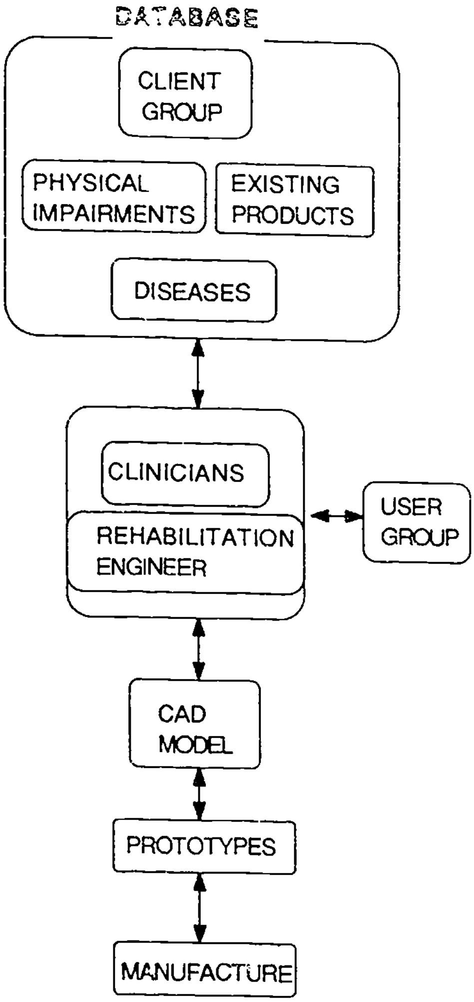
Traditionally a request has been generated by a group of users who may be linked through a relevant charity.After discussion and subsequent analysis a set of needs is identified and a proposal for research and development is made.Once the design and development work is underway the devices are evaluated with the intended users at every stage of the design and development process and the results statistically analysed.By the time a product is proposed to a manufacture it will have gone through several design prototypes.Unfortunately this approach does not take account of other user groups and for them much of the process has to be repeated.

## Production

Inevitably much of the manufacturing especially at the early stages ,is concerned with one off prototypes or short production runs.If items are to be produced in large quantities then commercial manufactures are involved at the earliest possible stage in the design process.

## Model.

The diagram shows how our approach differs from traditional design and manufacture.When a need is identified ,perhaps through a user group ,the system responds by accessing a database to put the user group into context.This is followed by the usual design processes as identified in an earlier paper[2].We emphasise the importance of computer aided design and associated databases ;the database involves inputs from clinicians and users as well as rehabilitation engineers.The data may be held in a variety of cross referenced files or a hypertext multimedia system.The system allows the designer to find information on the needs and requirements of a particular client group but this can be supported by accessing information on other client groups as well as related /existing products. This technique allows anthropometric information to be used without the need to continually repeat measurements.When user trials are involved, information from users may be stored for future use ,especially in a cross reference system so that although the original request came perhaps from a single user the needs of others are readily available.




Our development system makes use of the Delcam Duct CAD system ,a 3D engineering design suite ,which is based on a spine system, allowing complicated doubly curved surfaces to be drawn.For the conceptual stages of design ,this can be interfaced with the ALIAS surface modelling package which has high level surface rendering and animation capabilities.In this context we emphasise that concept is influenced by technical considerations as well as by visual impact and the initial stages of the design process in rehabilitation engineering are concerned with both aspects,.Accordingly ,development tools such as Aries Concept Modelling ,with interfaces into ADAMS and ANSYS are available to complement the form and texture design possible with ALIAS..The ADAMS suite of software is particularly useful for the dynamic and kinematic analysis of mechanical systems since it allows the designer to consider the implications of a range of mechanisms.

This modelling facility enables the rehabilitation engineer to avoid the need for extensive prototyping with the inevitable cost implications in materials and time[3].One valuable aspect of this change is the use of feedback from users to change the design at an early stage, with reduced trial and error ,and to obtain anthropometric data from user trials of prototypes.

Suppose ,for example ,that a mechanical device designed using such systems did not give the results expected.This would allow the designer to refine the data being used in order to redesign the device. An arm support system might be designed assuming a certain set of arm constraints and allowed forces ,but the result might well indicate that these assumptions were in error.Equally because of the progressive nature of diseases such as Motor Neurone Disease many designs have to take into account likely changes in constraints etc.This implies a consideration of possible adjustments to the mechanical device with the need for a design system which can make such judgments possible on an individual basis and for the whole range of possible variations.

Manufacture.

We have already identified the need for flexibility in design solutions so that devices and systems can cope with individual requirements .This may be in conflict with requirements of economic manufacture which invariably emphasise the desirability of uniformity in production runs.

Through CAD CAM packages such as ALIAS and DUCT it makes it possible to place equal emphasis on both the visual and functional aspects of a proposed solution within the context of manufacture and marketing. With the DUCT machine path generation software one can, proceed to production of either prototypes or small scale batches.The decision between the use of CAD/ CAM or traditional manufacture depends on the form of the device as well as cost.In some applications such as presentations to user groups ,clinicians and manufacturers,it may not always be necessary to produce a physical model.For this and for use for spatial fit tests, for which a solid object model is desirable , the technique known as stereolithography (SLA) may be appropriate.In the SLA technique the required form is modelled from the CAD package in polymerised plastic resin.The polymerisation being achieved through the use of a laser.Although such systems are expensive, they can be shared ,or perhaps hired ,so that the occasional user should not have to invest large capital outlays.In any event it seems likely that the cost of such systems is likely to continue to fall rapidly.

**Case Study**

Earlier this year we decided to focus our attention on the kitchen environment,as we identified this area as having the largest concentration of "specialist tools " and equipment in the domestic environment.The exercise also highlighted the extent to which we use our hands to control our environment.It follows that when hand disfunction does occur then use of the kitchen is severely curtailled.This is the case for many thousands of arthritis sufferers ,who experience great difficulty and pain when preparing,cooking and serving food. We discovered from demographic data that individuals with an arthritic condition form the largest group within the disabled population with a hand dysfunction. . Discussions with Arthritis Care identified two main groups: a numerically large group of elderly arthritics and a smaller group of Rheumatoid Arthritics.The latter group would benefit from new products in a different way to the more elderly group since they were often involved with employment and with younger families.We focussed generally on pans and cookware and specifically on pan handles,discovering that very little research in relation to anthropometric and ergonomic data existed. Drury[4] has discussed the forces acting on the hand when exerting a grip ,as on a handle.In a mainstream power grip the hand would be in a supinated position with the hand in a vertical plane .This transmits a large compressive load through the lower wrist to the ulnar forearm bone with the load acting about the central capitate wrist bone.

In a Rheumatoid hand there is dysfunction due to joint swelling and weakening of the supporting ligaments with erosion and crumbling of the bone itself.This leads to deformity,weak grip ,dislocation and severe pain.Discussions with Rheumatologists and specialist O.T's. indicated the need to carefully consider the forces and to reduce the compressive forces on the wrist. With this in mind the hand is to be used in a pronated position and the the index and middle fingers used to lift the load.To improve stability the less dominant hand would be used to lift the other side of the load thereby reducing the load on the main grip hand.The second hand would be in a supinated position but using the metacarpal of the index finger to reduce the load distance from the wrist and the forearm could be used to further reduce loadings.

The handle designs ,based on these ideas ,so far developed in collaboration with users and clinicians as described above , have been based on anthropometric and biomechanical data.As the handles are evaluated so this data will be updated for future use.They are currently being evaluated as indicated above in conjunction with clinicians. Although the designs will be specific to a particular user group they are seen as being accessible and desirable to a wide range of users . With a fully developed CAD system as described earlier the detailled forces involved can be determined and optimised.It will then be possible to modify the design ,analyse the modifications and rapidly prototype with confidence.This is currently under development.

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Robert Brown and David Wright.
Brunel Institute for Bioengineering
Uxbridge
Middlesex
U.K. UB8 3PH

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# A Model Regional Committee on Rehabilitation Engineering and Technology

James A. Lenker* and Patrick M. O'Quinn**
*Center for Therapeutic Applications of Technology, University at Buffalo
**Rehabilitation Association of Western New York
Buffalo, NY

## ABSTRACT

In January 1991, the Rehabilitation Association of Western New York (RAWNY) formed a sub-committee for the purpose of fostering increased interaction between the rehabilitation and engineering communities in the Western New York region. The Rehabilitation Engineering and Technology Sub-Committee met six times during 1991 and established itself as a dynamic, growing entity within RAWNY. Replicating this committee model could ultimately improve the transfer of technology from industry to the rehabilitation community, as well as increase the number of engineers who choose to specialize in rehabilitation engineering.

## BACKGROUND

The engineers who are involved in RESNA comprise an extremely small niche within the broader engineering profession. Engineers who are educated and employed in traditional disciplines have little knowledge about the needs of the rehabilitation community. Likewise, the rehabilitation professionals who are involved in RESNA represent a small fraction of their respective professions. Most "traditional" rehabilitation professionals have only a vague idea of the potential benefits of engineering technology.

The Rehabilitation Association of Western New York (RAWNY), like its parent organization the National Rehabilitation Association, is a, "private, non-profit, voluntary organization and strong lobbying force for the advancement of rehabilitation for all persons with disabilities." Its membership is comprised of rehabilitation professionals, primarily rehabilitation counselors. RAWNY formed the Rehabilitation Engineering and Technology Sub-Committee in January 1991 to develop links between the rehabilitation and engineering communities in Western New York.

The table below shows the charter membership. Diversity in technical disciplines, education levels, and industries represented on the committee was a consideration in filling out the committee.

| Discipline | Education | Industry |
|---|---|---|
| Mathematics | Ph.D. | Defense |
| Computer Science | Ph.D. | Defense |
| Mechanical Engineer | BSME | Toys |
| Rehab Engineer | MSME | Ass't Prof. |
| Software Engineer | BSEE | Electronics |
| Electrical Engineer | BSEE | Electronics and software. |
| Chemistry | Ph.D. | Defense |
| Rehab Counseling | BA, CRC | Mental Hlth |
| Rehab Counseling | MS, CRC | State OVR |
| " | Ph.D., CRC | Rehab Tech. |
| " | Ph.D., CRC | Ass't. Prof |
| Occupational Therapy | M.S. | Grad. Student |
| Business | Ph.D. | Dental |

## OBJECTIVES

The President of RAWNY developed a preliminary mission statement for the sub-committee that was subject to further input and slight revision by the RAWNY Board of Directors and members of the sub-committee. The final, board-approved mission statement for the Rehabilitation Engineering and Technology Sub-Committee included a broad set of long term objectives. These were to:

1. Explore and develop methods that will enable effective interfacing between participants from the technological and rehabilitation communities.

2. Assess the status of the rehabilitation community in regards to technological knowledge and use.

3. Develop strategies to strengthen rehabilitation practitioner and consumer understanding and use of technological equipment.

4. Suggest training opportunities to facilitate the application of technological advances to rehabilitation venues.

5. Familiarize engineering and business professionals and students with techniques and opportunities in rehabilitation.

6. Serve as consultants to the local community regarding availability and application of existing technological equipment.

7. Identify gaps in existing technology.

8. Create strategies for effective and/or creative technology transfer.

9. Serve as technological resources, if needed, for people with disabilities.

Initial committee objectives were: 1) share professional and personal interests in rehabilitation engineering, 2) share information to educate engineers about issues in rehabilitation and educate rehabilitation professionals about technical developments in industry, 3) develop a set of ethical guidelines for the sub-committee, 4) develop a plan for recruiting additional sub-committee members from the engineering community.

## METHODS/APPROACH

Since most members of the Rehabilitation Engineering and Technology Sub-Committee had not met prior to formation of the sub-committee, the initial meetings were "get acquainted" sessions. Meeting sites rotated to include the companies and agencies of as many sub-committee members as possible. Sub-committee members are encouraged to host meetings to acquaint other committee members with the work that they are doing.

The early meetings revealed that the sub-committee needed a common background of knowledge from which to proceed as a group. Subsequently, information on rehabilitation and assistive technology was provided in the form of article reprints and hand-outs to all committee members. Rotation of meeting sites served a similar function of developing common group experience.

Ad hoc "sub-sub-committees" were formed to develop ethical guidelines for the sub-committee and to outline goals for recruiting additional members.

## RESULTS

The Rehabilitation Engineering and Technology Sub-Committee met six times during 1991. By the end of its first year, the sub-committee had developed a solid base of membership for building future activities. The sub-committee developed its own mission statement, is establishing a set of ethical guidelines to define member conduct, and has begun looking at member recruitment through regional chapters of engineering societies. The Executive Board of the Rehabilitation Association of Western New York thought highly of the sub-committee and approved a year-end constitutional amendment stipulating that the sub-committee have official status as a permanent committee within RAWNY.

## DISCUSSION

Now that the initial phase is completed, the committee is developing specific opportunities to reach out to the community. One suggestion is to have the committee act as an informal "sounding board" of interdisciplinary consultants to undergraduate and graduate students involved in assistive device design projects. This has great potential for students, consumers and committee members alike. Students could learn from practical design suggestions and perhaps incorporate technology that is already being used into their designs. Consumers would benefit from better device designs. Finally, the committee members could gain satisfaction from making a contribution to technology transfer. A second suggestion is to have the committee also act as a sounding board to small companies who are developing assistive technology products. Again the committee could foster improved technology transfer to smaller manufacturers.

The role of the Rehabilitation Engineering and Technology Committee will remain one of education and not product development. A basis for interaction has been established that will yield many tangible benefits in the years to come. Many industries are feeling the concomitant effects of the current recession and a scaledown of our domestic defense effort. Predictably, many companies are exploring new avenues of product development. Committees modeled after this one, if widely replicated, would heighten awareness of the technical needs present within the rehabilitation community. Through direct consultation one would expect to see improved technology transfer between industry and rehabilitation. Lastly, the Rehabilitation Engineering and Technology Sub-Committee model would no doubt draw a number of engineers from "traditional" disciplines into the rehabilitation engineering field, and this development would strengthen the role of our discipline in the long run.

James A. Lenker
Center for Therapeutic Applications of Technology
University at Buffalo
515 Kimball Tower
Buffalo, NY 14214

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# Cognitive Predictors of Successful Powered Wheelchair Control in the Very Young Child

Donita Tefft MA, CCC-SP, Jan Furumasu BS, PT, Paula Guerette, PhD
Rehabilitation Engineering Center on Technology for Children
Downey, California USA

**Abstract**

Currently, there is little information available to therapists to indicate when a young child is cognitively capable of driving a powered wheelchair. This project seeks to identify the cognitive prerequisites to successful powered mobility in young (18-36 months), physically disabled children. Developmental skills which incorporate concepts acquired during Piaget's sensorimotor and early preoperational stages will be evaluated. Developmental skills will be associated with performance on a wheelchair driving test. Forty five cognitively intact children with severe physical disabilities will be evaluated. Information will be used to determine appropriate cognitive skill levels prior to placing a child in a wheelchair, to provide an age appropriate driver training program, and to provide documentation of wheelchair driving ability for funding purposes.

## Background

Over the past ten years, research has documented the developmental and psychosocial benefits of independent mobility for the severely physically disabled child (1,2). These benefits include improved self image, increased ability to participate in educational programs, and improved cognitive, social, and communication development (e.g., 3,4). Children as young as two years old have demonstrated the ability to operate a powered wheelchair safely with supervision (5,6).

There are a number of factors identified by clinicians which appear to influence a child's ability to drive. These factors include physical access, cognitive "readiness" in a number of skill domains, temperament, and dynamic integration of sensory input, motor control and cognitive processing. Improved pediatric power wheelchair technology has eliminated physical access as an impediment to driving. Cognitive capabilities, on the other hand, have been more difficult to evaluate in the very young, physically disabled child. Temperament also appears to influence successful driving performance. Anecdotal evidence indicates that children who are attentive, persistent, and motivated to perform tend to be more successful powered wheelchair drivers. Finally, dynamic sensory-motor integration, which entails perceiving and processing stimuli, motor planning, and reacting appropriately in a timely manner while moving in space, also contributes to successful wheelchair driving.

## Statement of Problem

Currently, no battery of tasks exists to evaluate a child's cognitive readiness to drive a powered wheelchair successfully. Apart from actually placing a child in a powered wheelchair and evaluating his or her dynamic performance, it is often difficult for therapists to determine whether or not a child has developed the cognitive skills necessary for driving. In addition to these cognitive skills, aspects of the child's temperament must also be considered. The objectives of the project are: 1) to develop an assessment battery which evaluates a child's cognitive readiness to drive, 2) to determine the influence of temperament on wheelchair driving success, and 3) to develop an age-appropriate wheelchair driving program to teach powered wheelchair driving skills to very young children.

## Approach

Input from developmental specialists and professionals experienced in early powered mobility was obtained in order to identify the cognitive domains relevant to wheelchair driving. The primary areas identified were problem-solving, spatial relations, symbolic play and object permanence. Next, an in-depth literature review was conducted in the areas of pediatric powered mobility and cognitive development. This information was used to develop a battery to assess the four areas identified above (2, 7, 8, 9). The battery, which incorporates schemes acquired during Piaget's sensorimotor and early preoperational stages, will assist in the evaluation of the cognitive skills needed for successful powered mobility. Activities and toys used in the battery have been modified to accommodate to the motoric disabilities of the children. Finally, a measure of each child's "temperament", including factors such as perseverance and frustration level, will also be gathered (10).

A powered wheelchair driving training program has also been developed. This program will test basic driving skills as well as integration of these skills in different environments. The driving training consists of sessions progressing from basic skills such as driving in a straight line, to performance in community settings with supervision.

The developmental assessment will be given prior to the wheelchair training program, and will subsequently be compared to the results of the final driving evaluation. This information will be used to determine the cognitive skills required for successful powered wheelchair driving.

Forty-five children between the ages of 18-36 months will participate in the study. All children will have severe physical disabilities that limit independent mobility but will demonstrate age appropriate cognition and learning abilities. Medical diagnoses will include muscle disease, spinal cord injury (quadriplegia), and congenital disabilities such as arthrogryposis or osteogenesis imperfecta.

### Discussion

Independent mobility allows young, physically disabled children to be integrated into appropriate educational programs which can lead to enhanced psychosocial and cognitive development. It is anticipated that the assessment battery will identify the cognitive prerequisites to successful powered wheelchair mobility. These cognitive skills can be targeted and developed through appropriate developmental activities administered by therapists and parents. Continued documentation of the importance of cognitive assessment for powered mobility will supplement clinical reasons for the provision of power wheelchairs to funding agencies and insurance carriers.

### Future Implications

Establishing baseline cognitive skills for physically disabled children who are cognitively intact may be useful for other populations. This assessment may be valid for the developmentally disabled individual, since studies have indicated that development occurs in the same sequence but at a different rate for that population (11).

For some populations who demonstrate adequate cognitive and motor skills for wheelchair driving (e.g, cerebral palsy), failure in dynamic wheelchair driving tasks may be due to other factors such as difficulty integrating sensory, motor and cognitive skills. The dynamic integration of skills is essential but is difficult to isolate as a factor affecting performance. Demonstrating adequate cognitive skills may help to isolate integration problems if these individuals fail in a dynamic driving test. Further research is needed in order to provide the appropriate intervention strategies for those with both cognitive (i.e., integration) and motor deficits.

### Acknowledgements

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Donita Tefft
CART
Rancho Los Amigos Medical Center
7601 East Imperial Highway
Downey, CA 90242

# Validation of a PC-Based Perspective-View Wheelchair Simulator

A. Todd Lefkowicz, Sullivan Diagnostic Treatment Center, Harris, NY
Walter W. Wierwille, Virginia Polytechnic Institute and State University, Blacksburg, VA

## Abstract

A PC-based perspective-view electric wheelchair simulator prototype has been developed to enable therapists to prescribe electric wheelchair control interfaces better. The purpose of this study was to validate the wheelchair simulator by comparing user performance with the simulator to user performance with an actual wheelchair. Four spinal-cord injured and four able-bodied subjects navigated the simulator and an actual wheelchair through similar courses. Analyses of variance were performed on performance measures such as Root Mean Square (RMS) path deviation, maximum path deviation, number of path crossings, completion time, and position in forty-five and ninety degree turns.

## Background

There are a great number of control interfaces available for electric wheelchairs. Because the suitability of a control interface is dependent both upon the characteristics of the control and the disabled user, the prescription of an interface for an individual is a non-trivial task.

The use of simulator has many potential advantages over the use of an actual wheelchair in the testing of a control interface. First of all, the simulator may be less expensive to obtain and operate than an electric wheelchair set up to accept a large number of control interfaces. Also, performance parameters could be more easily modified using a simulator. Quantified performance data are difficult to obtain using an electric wheelchair. A computer based simulator could collect quantitative data as it were driven. It would also not need a large amount of room in which to operate.

A second major benefit of a wheelchair simulator is that of increased safety. A wheelchair user would not be injured by a simulated collision. A therapist could safely try a number of control interfaces. With increased safety, user apprehension or fear might have less of a negative influence on performance.

A number of wheelchair simulators have been developed. A perspective-view simulator was found to be a good predictor of high speed wheelchair performance when performance was measured by number of collisions with the sides of a six foot wide course (Jarvis, Lotto, Staub, Young, and Verburg, 1987). McLaughlin, Scott-Taplin, Mathews, and Smith (1989) report another simulator that has been developed to assist with user training and evaluation.

## Research Questions

To demonstrate the usefulness of a simulator in predicting wheelchair performance, it is important to show that user performance on the simulator was not significantly different from performance on an actual wheelchair.

## Method

A course was laid out using border tape on the floor of a large room. The course contained straight sections of path, forty-five degree turns, and ninety degree turns. Subjects were asked to drive an Invacare Rolls Arrow as quickly as they could twice around the course, while maintaining accuracy. Subjects were also asked to drive a PC-based simulation of the Invacare Rolls Arrow around a simulated course of the same dimensions. Two versions of the simulator were developed for this experiment. The "On Simulator" gave the user the visual perspective of sitting in a wheelchair. The "Behind Simulator" gave the user the visual perspective of being behind the wheelchair so that the position of the rear wheels could be seen relative to the simulated course.

A spring loaded, paint-based crayon attached to the center of the wheelchair was used to trace the path taken by the subjects as they followed the course. From this trace, positional data, measured from the center of the course to the nearest quarter inch, was taken every six inches. The same positional data were recorded by the simulators automatically as they were driven.

Performance measures were derived from these positional data, The performance measures include RMS deviation from the center of the path, maximum deviation from the center of the path, number of times the center of the path was crossed, position of the wheelchair in forty-five and ninety degree turns, and time taken to complete two laps around the course.

Results

The mean RMS deviations for both the on simulator (3.6 in.) and the behind simulator (6.7 in.) were significantly different from the mean RMS deviation for the wheelchair (5.1 in) at $p<0.05$. The Pearson correlation coefficient was calculated to be 0.716 for the on simulator scores paired with the wheelchair scores and 0.746 for the behind simulator scores paired with the wheelchair scores.

The mean maximum deviation scores for the on simulator (12.0 in.) and the wheelchair (13.8 in) were not significantly different from one another. However, the mean maximum deviation score for the behind simulator (18.1 in.) was significantly different from the other two at $p<0.05$. The maximum deviation scores for the on simulator were correlated with those of the wheelchair with a correlation coefficient of 0.458. The maximum deviation scores of the behind simulator were correlated with those of the wheelchair with a correlation coefficient of 0.550.

The mean number of times the center of the course was crossed was not significantly different for any of the three devices. The mean score was 12.0 for the on simulator, 11.6 for the behind simulator, and 12.4 for the wheelchair. Interestingly, when scores for the on simulator were paired with scores for the wheelchair, a correlation coefficient of -0.400 was calculated. When the scores of the behind simulator were paired with the scores of the wheelchair, a correlation coefficient of -0.063 was obtained.

The position of the wheelchair in a forty-five degree turn, measured toward the inside of the turn from the centerline of the course, was the fourth performance variable recorded. The mean score for the on simulator (7.84 in.) was not significantly different from that of the wheelchair (6.81 in.) or the behind simulator (5.13 in.). The on simulator scores correlated with the wheelchair score with a correlation coefficient of 0.164. The behind simulator scores correlated with the wheelchair scores with a correlation coefficient of 0.113.

The mean position of the device in a ninety degree turn for the behind simulator (6.3 in.) was not significantly different from that of the wheelchair (9.3 in.). However, the mean position of the on simulator (17.2 in.) was significantly different from the other two. The scores of the two simulators were not well correlated with the scores of the wheelchair. The correlation between the on simulator and the wheelchair was 0.024. The correlation between the behind simulator and the wheelchair was 0.232.

The final score examined was the time taken to complete two laps around the course. The mean score for the on simulator (40.9 s.) was not significantly different from either the mean score of the wheelchair (38.49 s.) or the behind simulator (44.12 s.). However, the mean scores for the wheelchair and the behind simulator were significantly different from one another at $p<0.05$. The scores for the on simulator correlated well with the scores for the wheelchair with a correlation coefficient of 0.766. The scores for the behind simulator were correlated to those of the wheelchair with a correlation coefficient of 0.542.

## Discussion

Many subjects reported anecdotally that the simulators did not model enough inertia. Subjects also felt that the behind simulator was more difficult to drive than the on simulator. The significant difference between the mean RMS deviation for the on simulator and the wheelchair may have been due to the greater inertia of the wheelchair. Deviation of the wheelchair from the course was more difficult to correct because the user would tend to over-correct. While the behind simulator had the same amount of simulated inertia, it was reported to be more difficult to drive than the wheelchair because of its visual perspective. Although the mean RMS deviations were significantly different, the mean scores of the on simulator and the behind simulator differed from that of the wheelchair by only 1.5 inches and 1.6 inches respectively.

The maximum deviation scores for the on simulator and the wheelchair were similar. These scores were not as greatly affected by inertia as by visual perspective. The behind simulator yielded maximum deviation scores which were significantly larger than the other two devices.

The number of times the centerline of the course was crossed did not prove to be a sensitive measure of performance. None of the treatments had any significant effect on this dependent variable.

Neither simulator performed significantly different from the wheelchair in forty-five degree turns. However, the on simulator performed significantly different from the wheelchair in sharper ninety degree turns. This difference is thought to be due to the limitations of the display. That is, the user of the on simulator cannot see the position of the rear wheels with respect to the course, whereas the user of the actual wheelchair or the behind simulator can look downward for visual reference. The individual scores for position in turns had a large amount of variance. Thus, the correlations between scores obtained from the simulators and those obtained from the wheelchair were low.

The mean time taken to complete the course was similar for the on simulator and the wheelchair. Although the mean time taken to complete the course for the behind simulator was significantly different from the wheelchair at $p<0.05$, the actual mean difference was only 5.6 seconds.

Although some statistical differences were found between the performance measures obtained from the simulators and the wheelchair, the absolute value of these differences were usually small enough to be considered acceptable.

## Acknowledgements

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Todd Lefkowicz
Sullivan Diagnostic Treatment Ctr.
PO Box 840, Benmosche Rd.
Harris, NY 12742

# The Sliding Disk Control Interface
## A Successful Technology Transfer

J. Audet*, Y. Lozac'h, M. Montiglio*, D. Mauger, Y. Giasson*
Institut de réadaptation de Montréal, Montréal, Qc, Can.
* Orthofab, Québec, Qc, Canada

ABSTRACT
A control interface for powered wheelchairs has been designed, that simplifies the movement needed to operate it and offers stable support for the user's limb. This device is most often operated with the foot.

The device originated and was fabricated at a rehabilitation hospital. It presented many characteristic that made it an interesting prospect for broader commercialization.

The device was used and evaluated by seven cerebral palsied users. A new design, based on the original concept and suitable for manufacturing, was created in association with a wheelchair company.

INTRODUCTION

Two years ago, the technical aids department of this rehabilitation hospital created an innovation program to encourage the emergence of new ideas within a structured framework. One of the main object of this program was also to associate with manufacturers in the field to bring projects with potential for commercialization, from a concept stage to production.

This is what happened with the sliding disk control interface for powered wheelchairs [1]. This project originated at the rehabilitation hospital. It was successfully brought to term in collaboration with a local wheelchair company.

The sliding disk control interface is an alternative to a conventional joystick. The concept is based on the translation of a disk in a single plane area instead of the joystick's handle displacement in a spherical area. The control is mostly operated by foot but can also be controlled with the upper limbs. The device is modular. The first module consists of the sliding disc mechanism which is fixed to the footplate (or elsewhere if need be). The other module contains the electronic components, the on/off and speed switches and the indicator lights.

The disk control is mainly aimed at users presenting ataxia and athetosis, such as the cerebral palsied clientele.

The functional requirements for the sliding disk prototype where:

- To create a control interface that could be operated with another body part than the hand; mainly the foot.
- To create an interface that did not demand fine or complex movements from the part of the user.
- To offer a stable support for the user's limb.
- To be sturdy enough to withstand the forces exerted by a user or blows from the chair hitting obstacles. To withstand humidity and dirt.
- To be adjustable in position, for left or right use.
- To have minimal overall thickness for optimum ground clearance.

Several prototypes where conceived and fabricated at the rehabilitation hospital to fulfill the demand of it's clientele. Prospect of commercial production made it necessary to evaluate the controls for an eventual redesign.

EVALUATION OF THE DISK CONTROL INTERFACE

The prototypes were evaluated with seven users (4 men and 3 women), all presenting cerebral palsy with quadriparisia and choreoathetosis affecting mainly the upper limbs. Mean age was of 32 (± 8.6) years.

Only two of the seven users had previously owned a powered wheelchair before using the disk control. Both had controlled the chair using a joystick, in one case barefooted with the joystick fitted to the footrest; a makeshift solution at best. Mean year of use for the device was of 1.9 (± 1.6) years.

Set up and use of the disk control was similar in many cases. Six out of seven users operated the control with their foot. Five of the seven users operated the switches by hand. All users operated the on/off switch by themselves but only 3 operated the speed selector. For longer rides the speed had to be changed by a secondary user.

General appreciation of the device was very good. Five of the seven users were very satisfied with the disk control they used. The two that where not, cited reliability problems. The high satisfaction is understandable since many of these users could not have been independent in a wheelchair without this device.

The main disatisfaction with the device came from the lack of reliability. The disk control is subject to a lot of physical abuse because users lack coordination but have their full strength. Also the legrests of a wheelchair will be the first parts to hit obstacles. What's more, the disk control is close to the ground and is subjected to dirt, rain and snow.

COMMERCIALIZATION OF THE DISK CONTROL

As the demand for the disk control grew it became apparent that a manufacturer would be better suited to produce it.

Several characteristics of the disk control make commercialization interesting [2]. First and foremost, this project was need driven, a significant problem was identified, as well as a specific target population. No other commercial product readily adresses the problem at hand. Functional requirements were specified. User evaluation of the device was done. A commercially sound, standard design is foreseeable.

What's more, the rehabilitation hospital and this manufacturer have agreed on a long term association for product development which encourages the involvement of both parties and develops a working relationship. This association makes it possible to combine the clinical knowledge of the clientele and their needs with manufacturing know-how.

COMMERCIAL VERSION

The disk control has been redesigned to account for the inadequacies of the first prototypes taking advantage of the technology and manufacturing facilities available to this company. The commercial version stays however very close to the original concept.

This version is still comprised of two modules. The switch module can come with toggle switch for hand operation or push button for foot operation.

The use of a two speed switch instead of a 6 speed dial switch makes it easier for the user to change speed by himself. Maximum speed can be adjusted.

On the original prototypes, molded ABS plastic was used for the casings and footplate. The parts on the new design are all metal.

The casings are sealed, even around the disk opening to protect against the humidity and dirt.

Overall height of the disc has been reduced from 4 1/8" to 2 1/4", to improve ground clearance.

On the original version a fullwidth ABS footplate had rapidly replaced the standard wheelchair footplates because it offered more room for the encasing of the module and rigidified the overall legrests structure. The new version also has a fullwidth flip-up footrest.

Since the original prototypes where always furnished at the rehabilitation hospital, installation on the wheelchair had always been done on a one to one basis and many parts, especially the anchoring fixtures, switches and disk where customized. This was possible because the technical aids department had technicians to do this kind of work. The commercial version offers as much adaptability especially in regards to the positioning of the device without needing complicated modifications. The disk module can be positioned in width on the footplate. Cutting the footplate cover in two, to accomodate the module, is the only customizing that has to be done. Height, depth and angle positioning is obtained by adjusting the legrest.

Although the disk control is mostly used with the foot, it has been successfully used in it's prototype version, as an elbow control by a cerebral palsied user. It's potential as a hand or upper limb control is promissing since it can offer characteristics such as plane displacement and support for the limb, not found on a joystick. Use of the device can be foreseeable with other clientele such as quads, that lack manual dexterity but still have upper arm control.

The commercial version being modular, can still be customized for upper limb use. the disk can also be equipped with different fixtures such as toe block or elbow cup.

CONCLUSION

The new version of the sliding disk control interface looks very promissing, offering all the functional requirements of the original concept. It fulfills a need yet unanswered by other commercially available products. The technology transfer was successful mainly because the project had been need driven.

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Jean Audet
Institut de Réadaptation de Montréal
6300 Darlington, Montréal, Québec
Canada, H3S 2J4

# *VOCOMOTION* - AN INTELLIGENT VOICE-CONTROL SYSTEM FOR POWERED WHEELCHAIRS

Richard D. Amori
Computer Science Department
East Stroudsburg University
East Stroudsburg, PA U.S.A.

## ABSTRACT

For those who are unable to operate a powered wheelchair using a physical control mechanism, a voice interface offers an alternative approach to independent mobility. *Vocomotion* is a voice control system which gives the user the kind of sensitive control provided by a joystick, allowing a wide range of adjustments to the chair's speed and direction. It is constructed from inexpensive, commercially available components and is a compact, on-board hardware/software device powered completely by the wheelchair's normal batteries. For flexibility, the interfaces to both the wheelchair and the operator are designed to be tailored to accommodate a particular wheelchair and a particular operator. A variety of safety features are an integral part of the design.

Key words: voice interface, natural language interface, human-computer interface, artificial intelligence, wheeled mobility, personal transportation.

## BACKGROUND

The Widener Memorial School is dedicated to the education of severely physically-impaired children in Philadelphia. Most of the students use wheelchairs, but not all of them can use them independently. For those who cannot operate a powered wheelchair because they lack the strength or coordination to control a joystick, a voice-control system, especially one which provides intelligent support, would bring greater mobility and independence. Such a system would also be useful to a much larger population beyond the Widener School.

Our Artificial Intelligence Laboratory has developed such a system. We have had a long-standing interest in computer understanding of natural language and have designed and implemented several language-processing systems:

- a tool for building English-language interfaces (1)
- an English language understanding system for controlling robots (3)
- a tool for communicating with the deaf, accepting spoken English as input and producing a video display of American Sign Language as output (4)

The potential offered by such language understanding systems for serving the physically-impaired was described at an earlier RESNA conference (2). *Vocomotion*, our voice control system for powered wheelchairs, is one successful example of the class of operator-control problems discussed in that paper.

## STATEMENT OF THE PROBLEM

Many wheelchair users cannot take advantage of the independence offered by powered wheelchairs because they cannot control a joystick. Several alternatives have been tried (e.g., sip-and-puff), but they have problems of their own - lack of sensitive control, unhygienic interface, etc. Now, with recent advances in voice recognition technology and language understanding theory from artificial intelligence, together with the availability of low-cost, low-power-consumption microprocessors, it is possible to extend powered wheelchair mobility to a larger community of users. *Vocomotion* is proof that it can be done.

## DESIGN

*Vocomotion* is a stand-alone, on-board, intelligent voice control system for powered wheelchairs. It converts verbal utterances into electrical voltages using:

- a commercial voice recognition unit which converts raw speech sounds into computer-readable text
- a director unit with custom-built software and hardware which convert the text input into electrical output equivalent to that of a joystick (see *Fig. 1*).

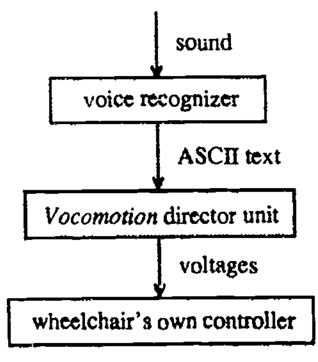


*Fig. 1*

*Vocomotion*'s software is designed to be independent of the many variations possible in the real world. It is designed for an abstract, ideal wheelchair world with interfaces tailored to a specific wheelchair and specific user. The mathematical model representing this ideal world is an augmented transition network which regulates permissible state changes. The natural language accepted is mapped by the intelligent software to a fixed set of model command categories which correspond to a set of "domain action primitives" described by Amori in his discussion of task-oriented discourse (3). The interfaces to a specific wheelchair and a specific user are contained in the Wheelchair Profile and User Profile, respectively.

## IMPLEMENTATION

Hardware: The microphone is Audio-Technica's AT810, and voice recognition is handled by Voice Connexion's Micro Introvoice product. The text output from the recognizer is processed by custom-designed software which runs on a Micromint RTC-V25 microprocessor. Additionally, several small custom circuits were designed to integrate *Vocomotion* into the wheelchair. The wheelchair used for the prototype is the Invacare Arrow XPR. An EEPROM is used to store profile information about the specific wheelchair and the specific user. All components are resident on the wheelchair and use the chair's normal batteries.

Software: The custom software is about 6,000 executable lines of 'C' code.

Costs: The wheelchair was donated; the cost of the Micromint boards and Voice Connexion product was about $2,150. This is the retail cost for the hardware and would certainly be much lower if *Vocomotion* were mass-produced.

## EVALUATION

The *Vocomotion* prototype has been constructed and has completed alpha testing at the University. A half-dozen users were trained and successfully operated the system during this period. Beta testing is now underway at the Widener Memorial School in Philadelphia, where physically-impaired children are being trained to use the system under the guidance of staff therapists. Preliminary results are very favorable - the operators are quite pleased with its performance.

## DISCUSSION

Many of the powerful features of *Vocomotion* can be illustrated by organizing our discussion around the issues of flexibility and safety.

One of the critical features in the system's design is flexibility. To illustrate:

- The user interface can be tailored to the individual operator. Parameters such as base speed and maximum speed can be set and later re-set according to the operator's maturity, physical condition, and experience with the system.
- The interface to the wheelchair can be tailored to a specific wheelchair.
- The operator is able to make both gross and fine adjustments to the chair's speed and direction. For example, a command like "Go fast" will accelerate the chair to full speed, whereas a command like "A little faster" will cause only a slight acceleration. Similarly, "Turn left" will produce a sharp turn, whereas "a little left" will produce only a slight veering.
- The operator need not be explicit about both speed and direction - the system will fill in the missing information. If the speed is not specified, the chair will either maintain its current speed or, if it is standing still, will use the pre-set base speed. If the direction is not specified, the chair will either maintain its current direction or, if it is standing still, will move in a forward direction.
- The operator is not limited to a single way of expressing a command - he can use a number of different phrases to express the same thought. For example, the phrases "Faster", "A little faster", and "Speed up" will all have the same effect on the chair's velocity.
- The operator's speech need not be clear to human listeners, as long as it remains consistent from session to session.

Another important design consideration was safety. With that in mind, the following safety features were built into *Vocomotion*:

- The system responds to a broad range of halt commands.
- Any command which is not recognized by the voice recognition unit, including inarticulate shouts, will bring the wheelchair to a halt.
- Commands expire after a certain time interval, so that if the operator should become distracted while the wheelchair is in motion, the chair will automatically come to a halt.
- The operator is able to indicate whether the

chair is moving within a confined or unconfined space. In a confined space, the system shortens the command expiration time, so that even if the operator does not have enough time to express a halt command, he will still be able to avoid collisions.

- The unit includes two emergency shutdown switches, one accessible to the operator and the other accessible to bystanders.
- To reduce interference from background noise, a noise-canceling microphone is mounted close to the operator's mouth on a headset.
- To avoid confusion between normal conversation and wheelchair commands, the operator is able to activate and de-activate the controller using two key phrases.
- The system is on guard for potentially destabilizing commands - for example, if a sharp turn command is entered while the wheelchair is moving quickly, the chair will automatically slow down.

## CONCLUSION

We have successfully constructed and tested an intelligent voice controller prototype. *Vocomotion* is a compact, wheelchair-resident system built from low-cost, commercially-available components which can be an add-on feature to a variety of currently available wheelchairs. It features flexible interfaces for both the wheelchair and the operator and exploits artificial intelligence techniques to infer missing information and detect and avoid potentially dangerous conditions. This allows *Vocomotion* to accept a wide variety of English utterances and provide sensitive control of a wheelchair. While designed for severely-disabled children, it is applicable to a much larger population: any wheelchair user who can speak.

Using *Vocomotion*, a wheelchair operator can maneuver smoothly and safely in a variety of settings - angling carefully up to a desk, moving quickly down an open corridor, threading through a crowded room, etc. - and can alternate safely between normal conversation and wheelchair control commands. *Vocomotion* can bring the experience of independent mobility to a wide population, allowing the severely-impaired to capitalize on whatever speaking skills they have.

## ACKNOWLEDGMENTS

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Author:

Richard D. Amori
Computer Science Department
East Stroudsburg University
East Stroudsburg, PA 18301

24.5

# DEVELOPMENT OF A 'SMART' POWERED WHEELCHAIR: A PROGRESS REPORT

Peter H. Gregson & R. Lee Kirby
Department of Electrical Engineering, Technical University of Nova Scotia
Division of Physical Medicine and Rehabilitation, Dalhousie University
Halifax, Nova Scotia, Canada


## ABSTRACT

A 'smart' wheelchair, a powered wheelchair which will respond 'intelligently' to sensor data, is being developed to 1) adaptively modify its operating envelope to compensate for variations in the user's control skills due to fatigue, changes in terrain, chair attitude or chair loading, to improve stability, comfort and performance; 2) perform real-time, short-range navigation using computer vision for persons who lack the necessary control skills for a conventional powered chair; and 3) be used as a test vehicle for the development of chair stability test and measurement procedures, and for the development of new chairs.


## BACKGROUND

Our overall goal is to improve the safety and performance of powered wheelchairs. The incidence of wheelchair use in the U.S. is about 3.3 per 1000 population; powered chairs (11) account for about 28% of wheelchairs (3). An estimated 26,000 wheelchair-related accidents, serious enough to seek attention at an emergency room, occurred in the United States in 1987 (8), for a rate of 3.3% of wheelchair users per year. The consequences of such wheelchair accidents may be simple sprains and lacerations, but 0.2% of these accidents are fatal (2, 4).

The rationale for 'smart' wheelchairs has been recognized for some time (5) and a number of groups have developed units with limited capabilities (1, 9). The state-of-the-art has been recently reviewed by Korba (6) and Nelson (7). At present, the powered wheelchairs that are commercially available are not capable of adequately modifying their operating envelopes on the basis of terrain, user performance, chair loading or other external variables. As a result, chairs do not provide the performance that they might, since chair performance must be selected a priori to handle the most likely cases, and chairs are not as safe as they might be because the chair cannot compensate for the co-occurence of destabilizing influences.

A second issue is the assessment of dynamic stability of current chairs and new designs. At present, the International Standards Organization (ISO) standards for the measurement and reporting of the dynamic stability of powered wheelchairs are difficult to carry out without a human operator. If using an anthropomorphic test dummy, it is difficult to have the wheelchair follow a known trajectory so as to induce the set of test forces necessary to induce the stability-defining tip. With a suitable set of control parameters for powered wheelchairs, dynamic stability standards may be further developed, and prototypes of new chairs safely tested.

Finally, there are a number of people for whom a powered wheelchair cannot be prescribed because they lack the necessary sensory, control or cognitive function for its safe use. These people therefore have little (if any) autonomous mobility, which has a major impact on the quality of their lives.

## STATEMENT OF THE PROBLEM

Wheelchairs must be equipped with the appropriate sensors and computational facilities to make them responsive to both the user and the immediate environment. Force transducers connected to an on-board data acquisition and control system will permit addressing the adaptive control and test vehicle issues. An on-board, real-time short-range navigation system is required to permit the prescription of powered chairs for persons previously unable to handle them.

## THE SMART WHEELCHAIR

The wheelchair we have been using has been an Everest and Jennings powered chair equipped with an on-board 6801-based microprocessor for data acquisition and control. We have instrumented it with four strain guages to sense wheel loading and four guages to sense seat loading, as well as possessing the joystick inputs and an RS-232-C input for data transfer and external control capability. The microprocessor monitors all strain guages and the joystick, both recording the measurements in internal memory and computing the next control action. Wheel loading and seat loading data are used to determine the stability margin of the chair, the stiffness of the user (which influences the control action) and the terrain.

The short-range navigation system will consist of a small CCD camera mounted on the arm of the chair, connected to an on-board computer system for processing the images. The on-board computer will use the optical flow field to attempt to find a safe path through the environment. This will include both obstacle avoidance, requiring extrapolation of the trajectories of identified objects in the scene, and collision avoidance, in which the system recognizes an imminent collision and stops. In more autonomous systems, the user will inform the chair of the eventual destination (the dining room, say). Based on internally stored 'world knowledge', the chair will formulate subgoals (turn left, go to the end of the hall, turn right,...). It will then proceed to achieve the subgoals in sequence. Visual input is again required to perform obstacle and collision avoidance.

## PROGRESS TO DATE

The data acquisition system is ready for initial trials. At present, the sampling rate is set to 1000 samples per channel per second. Input anti-aliasing is provided by second order filters with corner frequencies of 20 Hz. Experimentation with and without the filters are necessary to provide insights as to the optimal sampling rate and filter corner frequencies, since the complexity of the chair makes analytic determination of these frequencies difficult.

Development of suitable control strategies is proceeding. For instance, to avoid tumbling down a flight of stairs is conceptually simple; the chair merely needs to be stopped before reaching the edge of the top step. However, should the sensors detect an impending tip-over while traversing an incline, the appropriate response to avoid tip-over might be to steer downhill, but this could result in being struck by a passing vehicle. Modifying the chair-occupant configuration or deploying outriggers might be a more appropriate strategy.

The visual guidance system is approaching the end of the first phase of development. A method for determining the velocity field from identified 'interesting points' has been developed and is about to be evaluated on a variety of test image sequences. Some research into high-performance computing structures for velocity has been conducted, and simulations on components of one candidate architecture have been conducted. After further assessment, the architecture will be implemented in VLSI. In the meantime, however, further research on the visual guidance system will be conducted using PC-386 and PC-486 platforms and an HP-9000-720 RISC machine.

## WORK TO BE UNDERTAKEN

The data acquisition and control system will be installed on the wheelchair so that dynamic stability studies can commence and optimal control laws can be tested. The next phase of the visual system research is to segment the optical flow field to determine the boundaries of objects on the basis of their apparent velocities. Current strategies for finding free paths through a field of moving obstacles will then be studied so as to find one suitable for chair navigation. The visual guidance system will then be implemented in a combination of VLSI and software on a fast, physically small, conventional computer platform, so as to achieve real-time performance at minimum cost.

Successfully accomplished, we hope that this long-range project will provide valuable information to manufacturers, wheelchair designers and clinicians involved in helping disabled persons achieve greater independence and avoid serious accidents.

## ACKNOWLEDGEMENTS

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Peter Gregson
Department of Electrical Engineering
Technical University of Nova Scotia
P.O. Box 1000
Halifax, NS Canada B3J 2X4

24.6

# Patterns in Power Mobility Repairs: A Preliminary Report

Jim Fiss and Bruce Markmueller
Rehab Medical, Inc.
Aimee J. Luebben
University of Southern Indiana

ABSTRACT

Selection of cost effective product lines is critical to the viability of any company that markets assistive technology. Since breakdown incidence of power mobility systems, a high expense category for the rehabilitation technology supplier (RTS), varies from one manufacturer to another, a study was conducted to determine whether there is a pattern to power mobility unit repair. Additionally, replacement of standard tires was selected to examine the issue of whether third party payer funding of the lowest product in a category is cost effective over time.

## BACKGROUND

In the provision of assistive technology to a person with a disability, many members comprise the decision making team. As team members, the client and caregivers often do not know the variety of equipment that is available commercially. Many therapist team members are finding that the effort of keeping current with the various products of specific manufacturers has become increasingly more difficult in addition to the growing complexity of paperwork necessary to justify reimbursement requirements for adaptive equipment (Hansen, 1991). To fill this void on the assistive technology decision making team, many clinics are now likely to include at least one RTS. Rather than specifying the type of adaptive equipment needed, Margolis (1991) proposes that the client, caregivers, and therapists delineate precise goals that need to be met by the equipment and the RTS provides information regarding general types of technology available. Added to this primary role of information provision, the RTS is in the position to offer options, specific product specifications, characteristics, and performance capabilities.

While many of the team members work in the public or private health care system, the RTS works for or owns a business in the private sector. To remain a viable company in a competitive marketplace, the selection of cost effective product lines is critical. With many commercial product lines available today, the RTS must make decisions based on sound business practices.

Another factor added to the need for cogent product line determination, is the increasing sophistication of reimbursement sources. Obligated to curb escalating health care costs, third party payers are becoming cognizant of the need to determine the potential behind the recommendations for the purchase of costly durable medical equipment. In some states a growing trend for third party reimbursement sources seems to be a move to fix ceiling dollar figures on types of items or to fund the lowest product in a category. The drive for this type of cost containment often proves short-sighted and more expensive over time. Often the fixed ceiling amount precludes devices that prevent costly surgical procedures in the future and many times the lowest priced product requires more frequent repair and/or replacement. With a more costly initial charge, maintenance free items may actually be less expensive over a period of time.

In addition to the initial costs, reimbursement decision makers are paying more attention to failure rates, breakdowns, repair expenses, and part costs. Included in the high expense category of durable medical equipment are power mobility systems.

In 1989 three RTSs with combined 43 years of experience in adaptive equipment formed a new durable medical equipment company aimed at the rehabilitation market of the medical field with the mission of bringing assistive technology options into the decision making process of the clinical team; providing customer satisfaction throughout the evaluation, funding, equipment delivery and training phases; and delivering timely service.

## OBJECTIVES

The primary objective of the study was to help determine cost effective product lines by ascertaining whether there is a pattern to power mobility unit breakdown and also to see whether the systems of specific manufacturers or certain mobility types have higher rates of repair. Examination of the issue of whether funding the lowest product in a category is really cost effective across time was the secondary objective for this study. The need to replace standard tires, the lowest priced item in this category, was investigated to determine if maintenance free tires may actually be less expensive over a period of time.

## METHOD

A survey was conducted to determine whether there is a pattern to power mobility system repairs and to investigate whether the systems of specific manufacturers or certain mobility types have higher rates of breakdown. For each power mobility unit brought into the shop for repair a "Power Wheelchair Repair Survey," designed as an intake form, was completed by the electronics repair supervisor during the interview with the user. Six sections comprise the cross-sectional survey including specific information about the power system (manufacturer, type, serial number, and age), user's description of the problem, other problems found during servicing (if applicable), length of time needed to complete repairs, retail cost of replacement parts, and time and materials (if any) covered by warranty. A chi-square test of goodness of fit was conducted to determine if there were differences among the incidence frequencies of repair categories and descriptive statistics were utilized for the standard tire data.

## RESULTS

In the four months from July through November 1991, surveys were completed for the power mobility units delivered for repair. Four types of power mobility units (conventional, power base, three wheeler, and add-on power unit) from seven manufacturers were included in the total of 36 power mobility systems repaired during this time. Of the 36 power mobility units, the repairs showed a breakdown pattern that clustered into three mutually exclusive, primary problem areas: electronics, batteries, and mechanical. The batteries and electronics categories are self explanatory while anything not considered electronic nor battery related (e.g., tires) was grouped into the mechanical category. The batteries and mechanical categories each had eight power mobility units (22% per category for a total of 44%) that required repairs. Comprising all the repairs needed in the mechanical category, standard tire replacement on the eight power mobility systems averaged $161.88; the average age of the mobility units requiring standard tire repair was 1.56 years.

With 20 of the 36 (56%) power mobility units the electronics category showed a significantly higher need for repair than either the batteries or mechanical categories, chi-square $(2, n = 36) = 7.99$, $p < .05$. It should be noted a torn joystick boots, once a minor, inexpensive part to replace, left unrepaired either directly or indirectly caused the more costly electronics problems in 25% (five of the 20) of power mobility systems in the electronics category. A repair pattern among manufactors and among mobility types did not emerge with this sample size; however, the torn joystick boot that contributed to subsequent, more expensive repairs was found on several Invacare power mobility systems.

## DISCUSSION

In the cases of torn joystick boot, the problem moved from primarily mechanical to electronic and the increased numbers in the electronics category are indicative of this repair need. While the battery category would keep the same numbers regardless, if the joystick boot had been replaced before contributing to futher damage, the numbers of the other categories would have been different (an increase from eight to 13 in the mechanical category and a decrease from 20 to 15 in the electronics group). The changes would have shown a more even distribution among the categories and no statistically significant differences.
It should be noted that since the RTS owned company has had a high success rate with Invacare mobility systems and has sold more Invacare power mobility units, proportionally there were more Invacare power mobility units than systems from other companies in this study. However, the need to replace the boot was found for that manufacturer alone. Although the replacement boot from Production Research Corporation was noticeably thicker than the original factory boot and also featured a wider

flange at the base, there are no data on the success rate of the replacement boot. A simple solution to the joystick boot problem is the redesign of the original product to eliminate tearing and prevent subsequent electronics difficulties.

Apart from the electronics finding, other studies have shown similar results. In a study on powered wheelchair batteries Aylor, Byun and Kauzlarich (1991) determined that costly batteries are being replaced often in powered wheelchairs. Brubaker (1988) found batteries to be the component requiring the most frequent repair or replacement with the next highest problem component being tires. In the current study with the costs of maintenance free tires ranging from $65.00 to $110.00, these initially more expensive products proved more cost effective than the cheaper standard tires over time. Instances such as this may provide third party reimbursement sources with the information necessary to make an informed decision regarding cost effective products over time.

The 36 power mobility unit repairs in this study are preliminary data for a larger project. To collect the information necessary for determining which product lines to carry, the RTS owned business will continue to collect surveys.

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Jim Fiss, President
Rehab Medical
9481 Dielman Rock Island
St. Louis, MO 63132
314-432-1230

# AAC DEVICE MOUNTING SYSTEM FOR SUPINE STANDER

Brenda A. Sposato, M. Eng, Glenn Hedman, M.Eng, Patricia Politano, M.A., CCC-SLP
Assistive Technology Unit
University Affiliated Program / University of Illinois at Chicago
Chicago, Illinois USA

## ABSTRACT

To allow the individual with a disability to achieve greater independence, the rehabilitation engineering field must develop new technology to integrate separate pieces of commercially-available adaptive equipment. Specific to this paper is the essential need to integrate the use of an augmentative communication device with the simultaneous use of a supine stander. For the individual with a disability, time spent in a supine stander may mean time spent without accessibility to a voice- output communication device. As a result, this limits participation in activities both in school and at home. A custom mounting system was designed for interfacing the Prentke Romich Light Talker with a TherAdapt supine stander.

## BACKGROUND

At present, commercially available mounting systems for augmentative / alternative communication (AAC) devices exist only for wheelchairs and stable, level surfaces such as tabletops. Persons with severe physical disabilities frequently require alternate positions throughout the day to maintain optimal physiological function and integrity. These alternate positions often take the individual out of the wheelchair or away from the level surface on which he or she is accustomed to working. For example, the person might spend time in a supine stander, prone stander, side lyers, or in bed. In these cases, the lack of commercially-available mounting systems for AAC devices forces the individual to rely on another communication method. The individual may become dependent upon others to interpret yes/no responses or to read a manual communication board.

It is essential for the individual with a disability to be able to communicate in all environments. Communication allows an individual with disabilities to participate and to be included in all activities. Research has shown that factors determining successful use of technology (e.g., AAC devices) include not only meeting the individual's need for independence, but also that the device be easily accessible and easy to use[1]. The aesthetics of the technology is an additional factor. These critical factors must be addressed in the design and development process of new adaptive equipment.

J.J. is a bright, interactive seven year old with spastic quadriplegia cerebral palsy. He is mainstreamed at public school with the support of the Physical Health Impaired staff. J.J. communicates using the PRC Light Talker which is mounted to his wheelchair with the PRC Wheelchair Mounting Kit. He uses 32 row-column scanning with a single switch input mounted to his head support. J.J. tends to tilt his head to the right and can maintain neutral position for short periods of time during motivating activities.

J.J. uses a variety of adaptive equipment both at home and at school, and his positioning changes many times throughout the day. His daily school routine often includes alternating two hour periods of time spent in his chair and time spent in his supine stander. His Light Talker must be accessible to him in both situations to be included in all activities.

## DESIGN CRITERIA

J.J. and his family came to the Assistive Technology Unit (ATU) seeking a way in which to mount both his Light Talker and his single switch (TASH treadle) to his TherAdapt supine stander. The family explained that the stander would be used in both school and home settings and the mount would need to address four main issues.

- The family did not want the device to be mounted directly on the laptray surface as this would minimize J.J.'s available working space. It was also essential to his ability to properly scan as well as to activate a head controlled input switch that the Light Talker be mounted in line with J.J.'s eye gaze.

- The mount should be easily transferrable from J.J.'s wheelchair to the stander without having to readjust the height and angle of the device each time. J.J. is often repositioned by therapists, school teachers, and family members. Therefore, easy consistent transfer of the device was essential.

- For safety reasons and ease in transportability, the mount should be attached directly to the stander frame as opposed to a mount that would stand independently near the standing frame. J.J. is mainstreamed at school and to avoid potential injury to a passerby or to the device itself, it was essential that the mount be a stationary part of the standing frame. The same reasons applied at home as J.J. has two younger siblings.

- The head support and positioning of the treadle switch needed to be customized. The current support offered by the standing frame consisted of a flat, padded insert that extended from the top of J.J.'s head to his buttocks. An additional pad was placed perpendicular to this pad on the right side offering essential lateral head support. J.J. required a head support / switch mount that offered a point of rest without switch activation.

## RATIONALE

The application of technology, from the rehabilitation engineering perspective, is analogous with the pyramid model presented by Richard Dodds[2]. The bottom layer includes the application of commercially-available devices that directly meet the individual's needs. The middle layer includes those commercially-available devices that, after undergoing adaptation, meet the individual's needs. The top and final layer includes the custom design and fabrication of devices to best meet an individual's needs. Although custom-design may be the least cost effective and most time-consuming option, it may be the only choice available in trying to provide a solution. For J.J., a custom-designed and fabricated solution, using as many commercially-available components as possible, seemed to be the most appropriate method.

## DESIGN AND FABRICATION

The design for the custom mount incorporated the criteria given by the family with emphasis on structural stability. The Light Talker, mounted to J.J.'s wheelchair, was to remain attached to the existing mounting pole (stainless steel pipe 3/4" ID, 7/8" OD) along with the existing shaft collar having a receptacle slot (3/8" x 1/4" x 1/4") to secure the pole to its mounting bracket. The receptacle bracket for the stander was fabricated as follows: (See figures 1, 2, and 3) Note that tubing lengths specified below were specific to the needs of the client.

- Three sections of stainless steel tubing (7/8" ID, 1" OD) in lengths 4-3/4", 13-1/2" and 32" were joined using aluminum structural slip-on fittings.
- Two rectangular floor flange fittings (1" ID, 1-5/16" OD) were attached to the base of the stander at 4-1/2" and 10-1/2", respectively from the front edge of the base, using round head machine screws, washers, and T-nuts.
- The 4-3/4" tubing was inserted into the flange at the 10-1/2" mark. The 13-1/2" tubing was inserted into the flange at the 4-1/2" mark. A spacer of galvanized steel pipe (1" ID, 1-1/4 " OD) was necessary to secure the fittings.
- Two adjustable T-fittings ( 1" ID, 1-5/16" OD) were attached to the 32" length pipe at approximately 7" and 19-1/2" heights with the above noted spacers. The T-fitting at the 7" height was attached to the 4-3/4" tubing. The T-fitting at the 19-1/2" height was attached to the 13-1/2" tubing.
- An plastic end cap was added to the lower end of the 32" tubing to protect floor surfaces from scratches.

FIGURE 1

- The upper end of the 32" tubing was fit with an adapted two piece stainless steel shaft collar (1" ID, 1-3/4" OD). The collar contained a protrusion that was compatible to the receptacle on the original shaft collar (of the original PRC mount). This locked the pole-mounted device in place. The protrusion was made by drilling and tapping the receptacle collar and inserting a 10-24 round head machine screw.
- Cylindrical foam insulation was installed over all exposed tubing sections for protective and safety purposes.

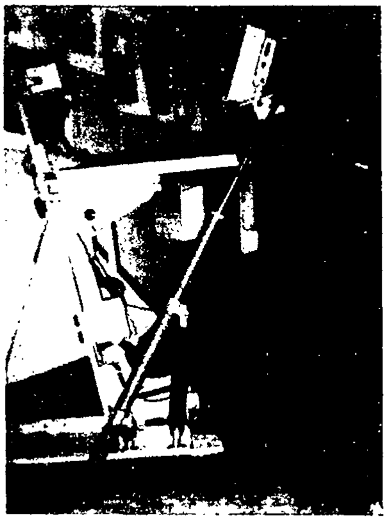

FIGURE 2

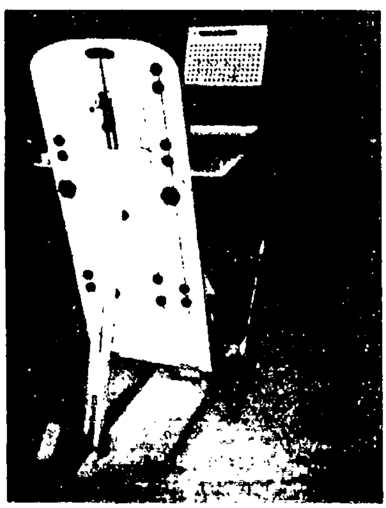

FIGURE 3

In addition to the device receptacle, a head support / switch mount was designed. A small commercially-available occipital angle bar was attached to the anterior surface of the stander with a 90° tube slide bracket and knurled knob. A kydex switch mounting plate (2-1/4" x 2-1/4" x 1/4") was attached to the occipital bar beneath the foam liner using a standard hose clamp (see figure 4).

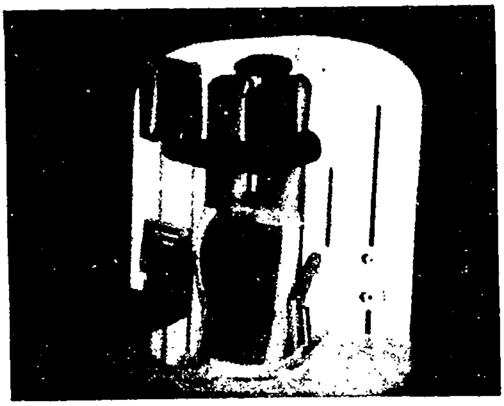

FIGURE 4

## DISCUSSION

The final fitting and adjustments to the system were made at the time of delivery. The optimal angle and height of the device were determined and the mount angles locked in place using the set screws of the structural fittings. The total cost of the materials involved for the device receptacle mount was approximately $35, and for the head support approximately $70. The entire adaptation was performed in approximately 2-3 hours.

As a result of this mounting system, J.J. is now able to use his Light Talker throughout the school day regardless of his position. Time in his supine stander no longer means time unable to access his voice-output communication device. He is now able to alternate positions throughout the day while maintaining independent communication.

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## SUPPLIERS

McMaster-Carr Supply Company
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| Adjustable T-fitting | 4698T97 |
| Two-piece shaft collar | 6436K38 |

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| Item | Item # |
|---|---|
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| 90° tube slide bracket | 1107 |
| Knurled knob | 3551 |

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- Hose Clamp

Brenda A. Sposato, M.Eng.
Assistive Technology Unit
University Affiliated Program
University of Illinois at Chicago (M/C 627)
1640 W. Roosevelt-Room 412
Chicago, IL 60608-1396
(312) 413-1555 (voice)
(312) 413-1326 (fax)
(312) 413-0453 (TDD)

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# DEVELOPMENT OF A LENDING LIBRARY OF COMMUNICATION EQUIPMENT FOR PEOPLE WITH AMYOTROPHIC LATERAL SCLEROSIS

Kathleen M. Smith, M.S.P.A., Kathryn Yorkston, Ph.D.,
Augmentative Communication Center, Department of Rehabilitation Medicine, University of Washington, Seattle, WA., Denton Kiehle, ALS Support Services, Kirkland, WA.

## ABSTRACT

Amyotrophic Lateral Sclerosis (ALS) is a progressive degenerative disease of unknown etiology involving the motor neurons of both the brain and spinal cord, As many as 75 percent of ALS patients are unable to speak at the time of their death. Providing expedient communication augmentation services to a population whose communication needs can change rapidly and frequently is a clinical challenge. One way of successfully meeting the ALS population communication needs is the creation of a Lending Library of Communication Equipment. Five years of experience with such a library will be described.

## BACKGROUND

ALS is a terminal progressive degenerative disease involving the motor neurons of both the brain and spinal cord while cognition and language remain intact. Neuropathology suggests simple atrophy, shrinkage and cell loss. The average world-wide incidence of ALS ranges between 0.4 and 1.8 per 100,000 with prevalence between 4 and 6 per 100,000. Mean age of onset is 56 years with a male to female ratio of 2:1. Speech characteristics vary depending upon the course of the disorder. If initial symptoms involve the bulbar nerves, motor speech and swallowing disorders may occur precipitously. If spinal symptoms occur first, speech symptoms will occur later in the disorder. Sitver and Kraat(1982) reported use of augmentative communication by 40 patients with ALS. Average time post-onset when augmentative communication was needed was 3 years (range 6 months to 10 years+). One third of these patients used systems for more than 2 years. In a recent survey of individuals with ALS, half reported that they wished to have more information about communication systems (Silverstein, et. al, 1991).

## OBJECTIVE

Previous experience with these patients has indicated that the usual procedure of seeking funding for communication equipment from insurance companies or Medicaid and ordering from companies was too slow. By the time the patient receives the new equipment, they may be unable to use it. The objective of this abstract is to describe the ALS Support Services Lending Library of Communication Equipment, the people who are referred, the operation of the library and its success.

## APPROACH

The ALS Support Services Lending Library of Communication Equipment began in 1988. Funding of the equipment was procured by ALS Support Services of Washington, a group providing information and support regarding ALS. They obtained an initial grant in 1988 of $25,000 for purchase of equipment. Since then, they have also provided $10,000 for more equipment. All equipment has been purchased by and housed in our hospital's Augmentative Communication Center. The lending library was organized to be accessible to any ALS patient in the state of Washington free of charge and would require a communication evaluation by a local speech pathologist or the speech pathologist in the hospital's Augmentative Communication Center. An ALS workshop, provided by our hospital in February 1988, helped to establish the lending library. Forty people from across the state attended the all day workshop. Most participants were speech pathologists. Procedures for a communication evaluation and for obtaining equipment were explained.

Since that workshop, the lending library has received referrals from the Neuromuscular Speech and Swallowing Disorders Clinic at the hospital, the ALS Support Services, MDA, speech pathologists and family or friends of the patient. ALS patients in the Neuromuscular Speech and Swallowing Disorders Clinic are rated on functional motor scales. The speech scale is from 1-nonspeaking to 10- normal speech. Generally at level 4 patients become concerned enough to request an augmentative communication evaluation. The scale scores for upper and lower extremity function for 105 visits for ALS patients with level 4 speech is highly variable Some considered motor functioning of their extremities within normal range while others considered both upper and lower extremities severely impaired. Thus a wide variety of communication equipment is needed to meet these motor needs.

General guidelines of the evaluation include an initial session of approximately one hour which is primarily informational. Communication strategies and equipment that might be immediately appropriate are discussed as well as a brief review of other equipment that might want to be considered at a later date. As appropriate, occupational therapy also assists to determine appropriate accessing methods.

The library encompasses a wide variety of devices which can be categorized according to the general function they perform. There has consistently been a high demand for attention-getting systems such as simple buzzers and/or nursery monitors. The library also includes speech enhancers such as a voice amplifier, loop tapes for use on the telephone and alphabet boards to supplement speech with the patient pointing to the first letter of each spoken word. In addition, there is written output capability with several Canon communicators, Casios and Sharp Memowriters. High tech equipment with speech and printed output include Words+ systems, LightTalker and Real Voice. Miscellaneous equipment includes headlights, eye gaze boards, switches, cables, ribbons, paper supplies and a miscellaneous fund is designated for repairs and supplies.

## DISCUSSION

Since 1988, 53 people have completed loan agreement forms indicating they have borrowed the equipment. Of those, 39 devices have been returned and 14 are still checked out. Length of time equipment is checked out is highly variable with some patients changing equipment during the progression of the disease. The average time with the same piece of equipment was six months or less. One patient continues to use daily the same system he started using in February, 1988. Patients from all corners of the state have borrowed the equipment.

Problems remain such as not having enough of the specific type of equipment patients are requesting and patients not being aware of the lending library. Thus, we are continuing to seek additional equipment and encouraging doctors and speech pathologists to refer patients to the ALS Support Services Lending Library of Communication Equipment.

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Kathleen M. Smith, M.S.P.A., C.C.C
Speech Pathologist
Augmentative Communication Center
Rehabilitation Medicine, RJ-30
University of Washington
Seattle, Washington 98195

# HABILITATION OF A CHILD WITH CLOVERLEAF SYNDROME

Charles J. Laenger, Carla Tiddy, Jacque Hodges
Susan Atkinson and Chris Bailey
Kaiser Rehabilitation Center
Tulsa, Oklahoma

Abstract

An eight year-old boy with very severe congenital defects was evaluated for equipment that will facilitate development of communication and environmental control capabilities and improve postural positioning. A means for eliciting environmental control and a precursor for developing communication was identified. A postural positioning approach was specified and a comprehensive report and budgeting estimate were submitted for approval.

## Background

T.D. is a deaf, blind, mute and non-ambulatory eight year-old boy. He likes to be touched and he enjoys being handled and cuddled by his loving parents. He can hold and suck a bottle with bifurcated handles using his polydactyl hands. He likes motion of a car or buggy and he particularly likes the harmonic motion of a swing. A homebound education program is provided by the local district, but progress is slow.

T.D. Has Good Head Control

One member of the habilitation team visited the client in his home to become acquainted with the family and to make a cursory evaluation. The team reviewed a medical study conducted by a geneticist and radiologist and others when the client was an infant. This study, entitled "Cloverleaf Skull Associated with Unusual Skeletal Anomalies" identified many skeletal anomalies (1). Brain stem auditory evoked potentials indicated profound hearing loss bilaterally. Similar studies indicated profound blindness in one eye and very low vision in the other. Even at this age, there was webbing over the popliteal areas. Physicians have been reluctant to recommend surgical intervention to correct any of these abnormalities.

An in-depth communication and environmental control, and a positioning evaluation were conducted at the rehabilitation center. Participants included the parents, special educator, vision specialist, occupational therapist, physical therapist, rehabilitation technician and rehabilitation engineer. The parents provided medical and developmental history of T.D. They described methods used in the home to feed, toilet, dress, entertain and care for this son. They also discussed his likes and dislikes and how he related to a younger, non-disabled brother. They listed positioning and communication as top priority needs. The special educators and vision specialist demonstrated the methods routinely used in the homebound stimulation and education program.

## Objectives

The major objectives were, (1) identify an approach to development of communication and environmental control, and, (2) specify an approach for development of positioning, mobility and transportation systems. One of the prime needs was to develop a plan and budgetary estimate that would facilitate acquisition of medical approval and submission to a suitable funding source.

## Approach-Communication/Environmental Control Evaluation

During interactions with the special educator, vision specialist and the father, T.D. used head nods to communicate approval, likes and dislikes. He used six to eight consonant vowel and vowel consonant combinations to communicate specific needs. But he demonstrated little overt effort to feel or manipulate, and thereby to control, his environment.

Battery Powered Swing
Modified For Remote Control

In order to elicit control activities by any communicatively impaired client, it is imperative to identify something that they like-and that they will actively seek. Harmonic motion provided by a simple swing was identified as that stimulus. Accordingly, a commercially available, battery powered swing was acquired and modified for remote switch control. When T.D. was placed in the swing seat and provided a momentary-on switch, he immediately understood that he caused the swinging action. He actively struggled to operate the switch that made the swing operate. He clearly expressed displeasure when the switch was removed and the swing stopped. Later, he resisted any attempt to remove the switch from his grasp.

The client was presented with a second momentary-on switch that contolled a vibrator. He clutched and, thereby, operated the switch and received a vibratory stimulus. He did not like this and attempted to push the second switch away.

T.D. Controlled The Swing.

Approach-Postural Position Evaluation

T.D. uses an old Safety Travel Chair which he has outgrown. The parents reported that it forces the legs in full abduction. His father reports that T.D. is uncomfortable with his legs in a neutral position. However, he did not demonstrate any stress when in the swing seat where he sat for about thirty minutes. The client was evaluated on the mat to determine range of motion, muscle tone and movement patterns.

T.D. Is Uncomfortable With Legs In Neutral Position.

T.D. Rejected Vibrator Stimulus

Severe Webbing in Popliteal Area

Results - Communication/Environmental Control Evaluation.

It is clear that continuation of speech-language therapy is justified. T.D. demonstrated an understanding of cause-and-effect and eagerness to initiate harmonic motion stimuli generated by the battery powered swing. He demonstrated the ability to seek and operate momentary-on switches. Therefore, it was recommended that various types of switches and switch mounting methods be utilized in controlling audio, light, vibratory and animated devices. This could be done in a systematic manner within the homebound education program under supervision of communications specialist.

Results - Postural Positioning Evaluation

A tilt-in-space wheelchair and a custom-contoured Beadseat seat and back were recommended. It may be necessary to fabricate and mount a frame for an integrated seat and back rather than using discrete seat and back modules.

A Columbia car seat was recommended for use when transporting T.D. by automobile. A walker or prone scooter, to be selected later, was included in the budgetary estimate.

Discussion

A comprehensive letter addressed to the referring physician and the school district administrator, was prepared and submitted. This included captioned photographs, description of the wheelchair and other equipment and cost breakdown. This will be submitted to a suitable funding source. Dr. B. Say, the geneticist who conducted the medical study for this client, will collaborate with the principal author to follow and document progress in the habilitation of this child.

Acknowledgements

Kaiser Rehabilitation Center funded the initial evaluation. The Bartlesville Schools of Oklahoma funded the in-depth evaluation and participation of the special educator and the vision specialist. The parents graciously provided information, and encouragement and made all participants feel comfortable.

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Charles J. Laenger, Manager
Rehabilitation Engineering and Orthotics
Kaiser Rehabilitation Center
1125 South Trenton
Tulsa, Oklahoma 74120
(918) 584-1351 X7347

P1.4

# A FLUSH MOUNTED TRAY SYSTEM FOR AN AAC DEVICE

Colin S. Twitchell, B.A. Adaptive Equipment Designer/Consultant
Susanne H. Shealey, M.S. OTR/L
Institute on Applied Technology, Communication Enhancement Center, Children's Hospital, Boston, MA

## ABSTRACT

Custom lap trays have been fabricated by an adaptive equipment designer/fabricator working with the professional staff with in a clinical setting. These custom trays were necessary because the commercially available AAC device mounts were not adequately meeting the needs of many individuals seen within this clinical setting. During the course of designing and fabricating many different custom tray systems it became apparent there were some standard features that most of the trays had. These features were analyzed and several prototype trays were made that embodied the results of the analysis. As time, testing and trial evaluation progressed, a tray system emerged that clamped on the wheelchair's frame. This proved to be the most versatile method for mounting the AAC devices.

## INTRODUCTION

This tray system evolved because the commercially available AAC device mounting options were generally inadequate for the non-speaking AAC device users seen in the clinical setting. The shortcomings of the commercially available mounting systems were as follows:

* Failure to provide a surface for the user's forearm support, a prerequisite for efficient physical access to the keyboard.
* Limited ability to use the mounting system for activities other than communicating.
* Limited interchangeability of the mounting system between user's multiple wheelchairs.
* Limited ability to properly position the AAC device to satisfy each users physical and visual requirements.
* Failure to provide adequate protection for the AAC device from moisture, impacts and other potential hazards.
* Limited versatility of clamp which secures the AAC device mount to the wheelchair frame. The custom tray systems were built in response to the individual needs of the non-speaking AAC device users seen by the center.

About two years after the first custom trays were built it was proposed that an attempt be made to develop and get manufactured a tray system that embodied the solutions to the problems with the commercial AAC device mounts. The various custom tray systems that had been built over the last two years addressed most of these problems, so this provided a starting point for a production tray. Aside from addressing the aforementioned problems the production tray system needed to be reasonably easy to make, be compatible with a broad range of wheelchairs and accommodate a number of AAC devices. After a year and several prototypes the production prototype was completed. The development of the production tray system appears to have been successful and it is the design of that tray system that will be discussed next. (figure 1) As a note, getting the tray system manufactured has to date been unsuccessful, but that is an other story.

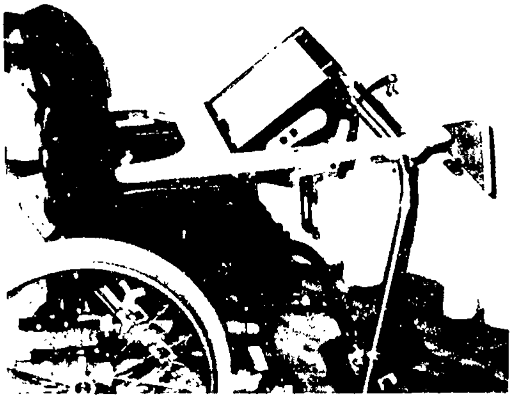

Figure 1

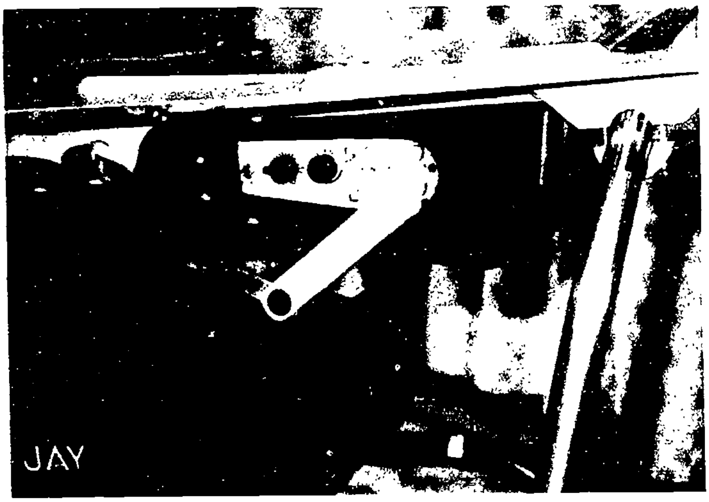


Figure 2

This socket allows the tube with the tray on it to be swung out to the side so that the
wheelchair user can transfer in and out of the
wheelchair. The socket is made so that it can
clamp on to 7/8" or 1" diameter frame tubing, additionally the socket allows the tube with the tray on it to be tilted forward and back.

**DESCRIPTION OF THE DESIGN**

In essence the production tray system consists of a rectangular flat tray surface 24" x 26" made from 1/4" phenolic which has a shallow stomach cut out in it and a rectangular cutout in it approximately the size of the AAC device that will be used with it. Attached to the tray surface is a cover that is hinged at the forward edge of the cutout for the AAc device receptacle and is the same size as the cutout. Bolted to the underside of the tray surface is an aluminum frame that supports a receptacle made from vacuum formed 1/4" A.B.S. plastic. In the receptacle is placed the ACC device. Thereceptacle pivots up through the tray surface by means of a pivot point formed by a hole in the aluminum frame through which a steel tube goes and is clamped to the back of the receptacle. A handle is attached to the end of the tube. This handle is used to raise the receptacle up and down. The handle is part of an adjustable latching mechanism that allows the receptacle to be angled from 0 to 45 degrees. (see figures 2 & 3) Also attached to the aluminum frame is a clamp that holds a 7/8" diameter tube with a 90 degree bend in it. This is the tube that holds the tray to the wheelchair. The end of the tube fits into a socket that is bolted to the wheelchair frame.

**FEATURES OF THE DESIGN**

In this section the more important features of the tray system's design will be discussed. The tray system can be easily moved from one wheelchair to another wheelchair that has a socket on it. This feature allows a user with two wheelchairs to use their tray system on both wheelchairs. This is accomplished by lifting the tube with the tray on it out of the socket on one wheelchair and placing it in the socket on the other wheelchair. The AAC device is protected from moisture by the vacuum formed receptacle and the cover in the tray surface. Protection from impact is provided by the tray surface, frame and tube that the tray is clamped to. In order to give the user a better viewing / keyboard angle the AAC device in the receptacle can be angled separately from the tray surface. The angle that the AAC device comes up to can be set by the user by means of the adjustable latching mechanism. Once the angle has


Figure 3

## FLUSH MOUNTED TRAY SYSTEM

been set the AAC device will repeatedly come up to that angle. To deploy the AAC device the user pulls back on the handle. This brings the AAC device up to the pre-set angle and locks it there. As the receptacle with the AAC device in it comes up from from being flush with the tray surface it pushes on a cam which opens the cover. When the user is done using the AAC device or wants an uninterrupted tray surface they can push the handle to the side which lets the receptacle back down below the tray surface. The cover is then closed by pulling a tab on the cam that opened the tray. Once the cover is back down over the AAC device it forms an uninterrupted surface with the tray. To provide better support for the user's forearms and a more functional placement of the AAC device the tray system can be adjusted in many ways. The height of the tray and how close it is to the user is adjusted at the socket. The angle of the tray surface and any offset needed to the left or right are accomplished by adjusting the clamp that holds the tray system to the bent tube. A final feature is that the socket and its wheelchair mounting clamp are fairly compact. Because the socket and clamp are compact there is a greater choice of mounting sites on the wheelchair.

### DISCUSSION

The tray system in its most current form has met with favorable criticism. The most resent prototypes have been circulated amongst OTs, PTs, communication specialists and adaptive equipment designers. Their positive comments have lead us to continue the development of the tray system and its manufacture. Some of the areas of development that we plan to explore are: fabrication cost reduction, easier installation on smaller wheelchairs, receptacles designed for lap top computers, and automatic cover closing.

### ACKNOWLEDGEMENTS

Institute on Applied Technology, Children's Hospital (Boston, Ma.)
Adaptive Design Services, Belchertown State School (Belchertown, Ma.)

Colin S. Twitchell, B.A.
55 Clark Street
Florence, MA 01060

# EMPLOYING THE CORNEA-RETINAL POTENTIAL DIFFERENCE TO CONTROL AN ACS

Joseph J. French, Arthur A. Siebens, M.D., and Donna C. Tippett, M.A.
Division of Rehabilitation Medicine, The Johns Hopkins University and
Speech-Language Pathology Department, The Good Samaritan Hospital
Baltimore, Maryland

## ABSTRACT

Eye blink switches may be difficult if not impossible to operate by an individual with locked-in syndrome.

It has been known for many years that vertical eye movements produce electrical potentials that can be picked up by surface electrodes placed on the skin near the eyes. To our knowledge no one has attempted to use these potentials to control alternative/augmentative communication systems (ACS).

This paper describes a device we have designed that amplifies and processes these potentials, allowing them to control a variety of communication devices.

## BACKGROUND

Loss of the ability to communicate is particularly catastrophic for individuals who are cognitively intact but are quadriplegic and have severe speech/oral motor impairments. Increasingly, technological advances have made it possible for such individuals to communicate using ACS (alternative/augmentative communication systems). These ACS typically capitalize on intact movement of the head, neck, eye or eye lid (1-4). One type of device uses the interruption of an infrared beam reflected from the eye during blinking as the output signal for controlling an ACS. Proper switch placement can be time-consuming and can require unusual expertise on the part of the caregivers. These requirements result in lack of carryover of the ACS into everyday living (5, 6).

## STATEMENT OF THE PROBLEM

The control of volitional eye movements is organized in the central nervous system in such a way that vertical motion of the eye can be preserved despite loss of volitional horizontal motion. Lesions of the brain occasionally result in losing control of all muscles, i.e., those of the extremities, trunk, neck and head, except for vertical eye motions.

This problem was experienced by a former patient with "locked in" syndrome. She was a 31 year old woman with quadriplegia and anarthria, status post resection of a cavernous hemangioma on 5/10/88. Following surgery, the patient demonstrated only vertical eye movements. The patient was admitted to our acute rehabilitation unit in 1989 and learned to use a row/column scanning ACS with an infrared eye blink switch. In 4/89, the patient was discharged to a nursing home. She experienced multiple medical complications, including a left tarsorrhaphy and a loss of sitting ability. When the eye blink switch was placed on the right lens of her eyeglasses, the patient could not see her ACS clearly. The switch could not be activated on the left. The loss of sitting ability precluded proper positioning to access the ACS. The patient was readmitted to our rehabilitation service on 9/24/91. Our challenge was to develop a switch which would access an ACS via vertical eye movement and require minimal time for setup.

## RATIONALE

Mowrer, Ruch and Miller (1936) demonstrated conclusively that the retina polarizes the eye, the posterior or retinal surface of the eye being negative with respect to the anterior or corneal surface (7). Motions of the eye are therefore associated with field effects which can be picked up by electrodes placed at right angles to the axis of ocular rotation. This electrophysiologic phenomenon is commonly used for identifying the sleep state characterized by rapid eye movements (REM sleep).

In an evaluation procedure, electrodes were applied to the patient as shown in Fig. 1 A. These were connected to a physiological preamplifier. The active electrode which went to the noninverting input was placed approximately one centimeter out from and one centimeter above the corner of right the eye. The active electrode which went to the inverting input was placed approximately one centimeter out from and one centimeter below the corner of the right eye. The indifferent electrode was placed behind the right ear over the mastoid. The patient demonstrated ability to generate reliable signals on a physiological recorder monitor. An upward movement of the eye produced a positive signal and a downward movement produced a negative signal. These signals were in the 50 to 100 microvolt range.

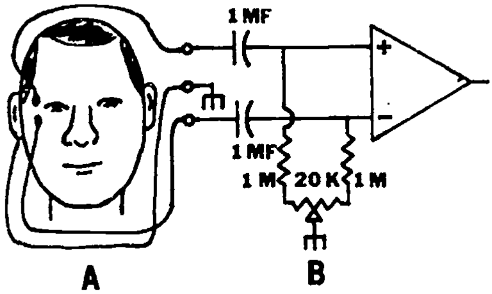


Figure 1. Electrodes and preamplifier

## DESIGN

Either the positive or negative signal could be used to produce a control pulse. However, in order to avoid false signals, the patient would have to stare straight forward while the device is in use, an obvious impracticality. The circuit is designed to respond only to a combination of these movements and in a very restrictive format, i.e. a quick upward movement of the eye followed within approximately one half second by a quick downward movement of the eye. Very few artifacts generated by normal eye movements follow this sequence.

*Safety considerations*
Since the sensors are low impedance electrodes connected to the patient, it is imperative that the sensing device be totally self contained and in no way electrically coupled to any other device. This is accomplished by making the device battery operated and coupling to another device through an infrared light emitting diode.

*Extraneous noise elimination*
The resistance of each input (noninverting and inverting) is one megohm. As shown in Fig. 1 B, the active electrodes are coupled to the patient through two matched (1%) one microfarad capacitors in order to block the D.C. potentials originating in the contact of the electrodes with the skin. If not blocked these would mask the eye movement potentials. This error is further reduced by trimming the input resistors (Fig. 1 B) to make the time constants of the inputs identical. This assures that the capacitively coupled and direct coupled common mode rejection ratios are both 100 dB (especially at 60 Hz).

*Sequence of operation*
The following description refers to Fig. 2 (Circuit) and Fig. 3 (Waveforms). The waveforms shown in Fig 3 are idealized in order to more clearly illustrate the operation and timing sequence of the circuit.

AMP 1 is a differential preamplifier with a gain of 100. It amplifies the raw eye movement signal (A). LPF and HPF are simple resistance-capacitance low pass and high pass filters respectively with an approximate cut-off frequency of 16 Hz. for LPF and 3.4 Hz. HPF. (B) indicates the filtered eye movement signal (most of the artifacts eliminated) at two levels of amplitude: 1) the output of LPF/HPF and 2) this output amplified by AMP 2. AMP 2 is a noninverting variable gain amplifier. Its gain ranges from X 40 to X 200 and, in practice, is set for optimal operation of the circuit.

The output of AMP 2 (B) is fed into the inputs of CMP 1 and INV. CMP 1 is a voltage comparator the output (C) of which is high when its input (B) is less than 1.2 V. As shown in (C), it generates a fast fall time when the positive portion of the eye movement signal (B) reaches 1.2 V. This fast fall time is necessary to trigger TMR 1. Its output (C) will remain low until its input (B) drops below 1.2 V.

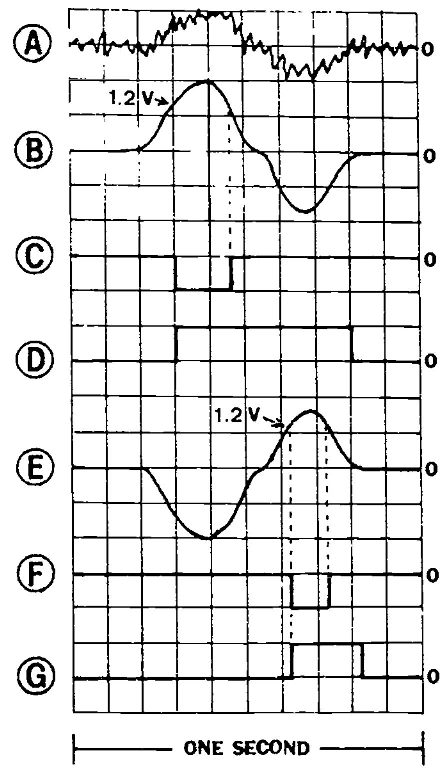

Figure 3. Waveform

TMR 1 is a variable duration timer which controls the gate in COMB. It generates a time window (D), optimally about one half second, limiting the time in which the negative portion of the eye movement signal has to be initiated. If not initiated within this time, no trigger signal (F) for TMR 2 is generated.

INV is an inverting amplifier with a gain of one. It is necessary to invert the eye movement signal here (E) because the comparator used in COMB will not respond to a negative signal.

COMB is a combination comparator and time gate. Three events are necessary to obtain an output (F): 1) the timer

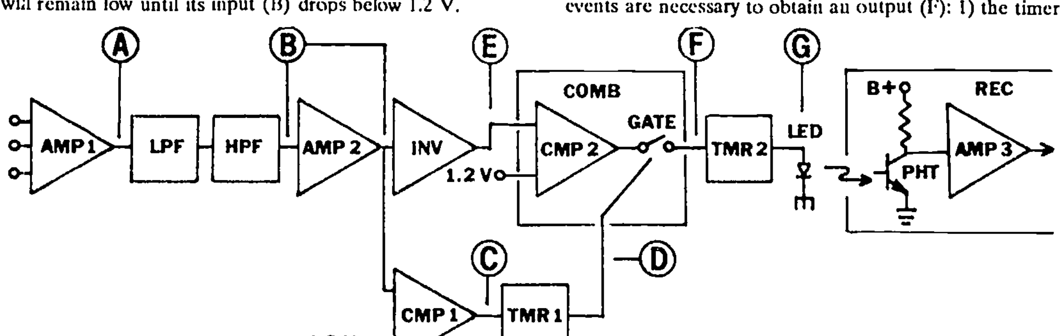

Figure 2. Circuit

pulse from TMR 1 must be present to open the gate (close the "switch"), 2) the inverted negative portion of the eye movement signal from INV (E) must be present, and 3) this signal must be at least 1.2 V.

TMR 2 is a variable duration timer that generates a pulse (G) which is independent of the duration of the COMB (comparator/time gate) output. It is used to drive LED which is an infrared light emitting diode which is the eye movement detector's link to the outside world.

REC is the receiver for the light emitting diode output. PHT is an infrared sensitive photo transistor, which is insensitive to ambient room light. AMP 3 amplifies the transistor output to a level required for controlling another device, e.g. a computer, a voice communicator, etc.

## DEVELOPMENT

In its present form the receiver must be approximately one inch from the transmitter (eye movement detector). This is because the diode is driven by a low current in order to reduce battery drain. If the light emitting diode where to be driven by a higher current, the spacing could be several feet.

The filters used in the present design are very crude. An active bandpass filter would be more selective in distinguishing between the physiological signals and artifacts.

## EVALUATION

The initial interface, for training purposes, was with an electronic timer which controlled a solid state relay. A small lamp connected to the output of the relay would light for one second when the proper sequence of eye movements was performed. A light was chosen rather than an audible signal because the patient had a severe hearing loss.

Placement of the electrodes required less than 5 minutes. They did not need to be placed in highly specific locations or require preparation of the skin. The electrodes used were Sentry Medical Products (8) No. 1030. They can be worn all day without discomfort or damage to the skin. The electrodes were not in the patient's line of vision.

## DISCUSSION

This device met criteria needed for facilitating carryover of ACS: reliability and minimal setup time. In addition, the device was durable and the electrodes low cost.

Ocular phenomena have been incorporated in response technology for severely impaired individuals. We are unaware that the cornea-retinal potential difference has been used before in this context. Although the application in the present instance pertains to a patient whose only remaining volitional act was vertical eye motion, applications would be of interest for less compromised individuals with impaired output functions.

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Joseph J. French
The Johns Hopkins University
Division of Rehabilitation Medicine
5601 Loch Raven Boulevard
Baltimore, MD 21239

P1.6

# A DESCRIPTIVE STUDY IN THE USE OF HIGH QUALITY PORTABLE SPEECH SYNTHESIZERS IN PHONE COMMUNICATION WITH PREPARED AND UNPREPARED LISTENERS

Eddy Ehrlich BSME, M.A., OTS
Occupational Therapy Department
New York University
New York, NY

ABSTRACT

Effectiveness of synthetic speech in functional speakerphone communication varied over a broader range than the intelligibility rates found in previous studies. The DecTalk, SmoothTalker and RealVoice synthesizers ranked by effectiveness, however, compared favorably with the published ranking by intelligibility. Use of preparatory digitized introduction as a means to increase successful communication had significant positive impact on the least effective synthetic voice and negative influence on the most effective voice. Moderately effective voices benefitted slightly from listener preparation.

## BACKGROUND

Voice output communication aids (VOCAs), are a modern means by which dysarthric and non-verbal persons can perform essential activities such as telephoning for information.

Many augmentative communication systems rely on text-to-speech electronic synthesizers which convert entered strings of characters into words and sentences by following preprogrammed mathematical alogrithms and pronounciation rules. Portable augmentative communications systems are now utilizing high quality computerized speech synthesizers such as DecTalk, RealVoice, and SmoothTalker. The adult intelligibility rates under laboratory conditions for these speech synthesizers are outlined in table 1. (Mirenda & Beukelman, 1987, 1990)

Table 1.
Intelligibility of Synthesized Speech

| | Single Word | Sentence |
|---|---|---|
| DecTalk Paul | 78% | 97% |
| DecTalk Betty | 82% | 96% |
| SmoothTalker 3.0 | 64% | 92% |
| RealVoice Female | 54% | 78% |

The aim of this investigation is the comparative effectiveness of speech synthesizers under the practical conditions of functional telephone communication with both prepared and naive listeners. Many VOCA users have multiple physical handicaps, therefore this study used a speakerphone to simulate hands-free phone communication. The preparation of a naive listener with an introductory remark will be tested as a strategy to increase comprehension of initial VOCA speech.

As in the real world, effectiveness of phone communication will be measured by more than mere intelligibility, rather by functional response; the completion of a requested task. Awareness of the functional effectiveness of this technology will help health professionals have realistic expectations of VOCAs and continue to make appropriate equipment recommendations.

### Problem Statements

1) How effective are the tested high quality portable speech synthesizers with unexpecting partners in phone communication?
2) Does preparation of the listener with an introductory digitized remark make initial functional communication via speech synthesizer more effective?

## METHOD

The functional communication task utilized in this study was requesting an address and telephone number from information operators in the 212, 718, 516 and 914 area codes. Effectiveness of communication was measured by the degree of proper delivery of the requested information. The actual phrasing of the request was, "Hello, may I please have the address and phone number of the Department of Motor Vehicles in Manhattan/ Brooklyn/ Westbury/ White Plains?".

The five voices evaluated in this study were DecTalk (Paul & Betty), SmoothTalker and RealVoice (Male and Female) which were chosen not only for their relatively high intelligibility, but for adult listener preference of these voices. (Crabtree et al., 1990) This study used various VOCAs which utilize these voices. DecTalk emitted by Multivoice[1] version 1.1, and RealVoice Female produced by Realvoice PC[2], were controlled by a Personal Computer VOCA software product called EZ

Keys[3]. The RealVoice Male was produced by the EvalPac[4], SmoothTalker by the VOIS 160[5], and the digitized voices were reproduced by the Macaw[6].

All the speech synthesizers spoke sentences which were adjusted by phonetic spelling or utilization of an exception table to maximize their output performance. In accordance with Easton's (1985) conclusions, all functional requests avoided single words or short phrases but instead were formulated as full sentences to enhance listener comprehension.

A digitized recording of human voice requesting the telephone number and address was used in 12 trials to establish a baseline of communication effectiveness for this experimental design. Each of the subsequent five voices was utilized in 24 trials, 6 for each area code. Half the 120 synthetic speech trials incorporated a digitized introduction and half used synthesized speech with no listener preparation.

All synthetic voices were spoken through the same Realistic model 21-549 external speaker. The volume in all trials was moderately loud, measured and compared by the microphone of a voice-activated tape recorder. In all the trials, the same Sanyo model AD200 speakerphone was used. The access method on all the VOCAs was direct selection.

Operational Definitions

Preparation of the listener by digitized message about the imminent use of a speech synthesizer was defined as follows:
"0" represents no introduction.
"1" represents full introduction. The augmentative user plays a audio recording of digitized voice which says, "I cannot speak, I am going to use an artificial speech synthesizer".

Effectiveness of communication when requesting performance of a simple task was defined as follows:
"0" represents ineffective communication. Task is not done, user is asked to repeat all or part of the request.
"1" represents partially effective communication. Task is done incompletely.
"2" represents effective communication. Task is done appropriately.

RESULTS

Baseline results which utilized digitized natural voice, revealed that for this experimental design, a maximum full effectiveness of 83% could be expected. While not always fully effective, the baseline results showed that natural voice was statistically never wholly non-effective (Table 2). Partial effectiveness in all the trials was only the result of the operator's giving the phone number but not the address.

Table 2.
Natural Voice Baseline Effectiveness

| | # of Trials | % of Trials |
|---|---|---|
| Fully Effective | 10 | 83% |
| Partially Effective | 2 | 17% |
| Non-Effective | 0 | 0% |

As outlined in Tables 3-7, none of the synthesized voices equalled this level of communication effectiveness. There was a broad range across the speech synthesizers. In full effectiveness, DecTalk Paul, the synthetic voice with the highest value, was only half as successful as natural voice. RealVoice Female was non-effective in 75% of the trials.

Table 3. DecTalk Paul Effectiveness

| | # of Trials | % of Trials |
|---|---|---|
| Fully Effective | 10 | 42% |
| Partially Effective | 13 | 54% |
| Non-Effective | 1 | 4% |

Table 4. RealVoice Male Effectiveness

| | # of Trials | % of Trials |
|---|---|---|
| Fully Effective | 8 | 33% |
| Partially Effective | 13 | 54% |
| Non-Effective | 3 | 13% |

Table 5. DecTalk Betty Effectiveness

| | # of Trials | % of Trials |
|---|---|---|
| Fully Effective | 5 | 21% |
| Partially Effective | 14 | 58% |
| Non-Effective | 5 | 21% |

Table 6. SmoothTalker Effectiveness

| | # of Trials | % of Trials |
|---|---|---|
| Fully Effective | 7 | 29% |
| Partially Effective | 6 | 25% |
| Non-Effective | 11 | 46% |

Table 7. RealVoice Female Effectiveness

| | # of Trials | % of Trials |
|---|---|---|
| Fully Effective | 6 | 25% |
| Partially Effective | 0 | 0% |
| Non-Effective | 18 | 75% |

Both fully and partially effective communication could be considered generally effective. That is,

General Effectiveness = Full Effectiveness + Partial Effectiveness

Table 8 shows general effectiveness for all tested voices.

Table 8.
General Effectiveness of All Voices

| | General Effectiveness |
|---|---|
| Natural Voice | 100% |
| DecTalk Paul | 96% |
| RealVoice Male | 87% |
| DecTalk Betty | 79% |
| SmoothTalker | 54% |
| RealVoice Female | 25% |

This study also sought to examine the influence of the use of an introductory digitized remark prior to synthetic speech communication. Table 9 outlines the general effectiveness of each synthetic voice with and without natural voice introduction.

Table 9. General Effectiveness and Preparation of Listener

| | General Effectivenes Without Introduction | General Effectiveness With Introduction |
|---|---|---|
| DecTalk Paul | 100% | 92% |
| RealVoice Male | 83% | 92% |
| DecTalk Betty | 75% | 83% |
| SmoothTalker | 50% | 58% |
| RealVoice Female | 17% | 33% |

DISCUSSION

The results of this study indicate that there is a broad range in the functional effectiveness of different synthetic speech synthesizers in speakerphone communication. Full effectiveness ranged from DecTalk Paul at 42% to DecTalk Betty at 21%, and general effectiveness from 96% to 25%. As expected, these range of these results were broader and the values were lower than the laboratory sentence intelligibility results. Though not quantitatively comparable, the ranked order of voices is the same in both studies; DecTalk Paul, DecTalk Betty SmoothTalker and RealVoice Female.

Except for Smoothtalker which was partially effective 25% of the time and RealVoice Female, which seemed to be either fully effective (25%), or mostly non-effective (75%), the synthetic voices were partially effective about half the time; DecTalk Paul (54%), RealVoice Male (54%), and DecTalk Betty (58%). It seems that in these cases the operators were able to understand "Department of Motor Vehicles" but did not discern that the request had been for not only the phone number but the address as well.

This might indicate that the communication barrier in these partially effective cases was no longer an issue of speech intelligibility alone. Rather, perhaps the hearing of an artificial voice was simply a distracting experience, resulting in the less-than-efficient task completion of leaving out the address.

A digitized introductory remark improved general communication effectiveness for all synthetic voices except DecTalk Paul. The most poorly effective voice in this study, RealVoice Female benefitted most from the introduction, raising its general effectiveness from 17% to 33%.

More investigation in functional communication with portable VOCAs is warranted. Face-to-face and less insulated interactions may result in significantly different communication effectiveness. Further study in the formulation and use of introductory preparation of VOCA listeners is needed to determine how it is most helpful.

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FOOTNOTES

1. MultiVoice is a hardware peripheral product from I.A.T., Inc.
2. PC RealVoice is a hardware peripheral product from ACS, Inc.
3. EZ Keys is software from Words+, Inc.
4. EvalPac is a dedicated VOCA product from ACS, Inc.
5. VOIS 160 is a dedicated VOCA product from Phonic Ear, Inc.
6. Macaw is a dedicated VOCA product from Zygo Industries, Inc.

Eddy Ehrlich
459 Columbus Avenue Suite 165
New York, NY 10024

# Sound-to-Speech Translation Utilizing Graphic Symbols

Carrie Brown, PhD, The Arc, Arlington, TX
Maggie Sauer, M.S.,CCC-SpL, University of North Carolina, Chapel Hill, NC
Al Cavalier, PhD, University of Delaware, Newark, DE
Catherine Wyatt. The Arc, Arlington, TX

Abstract

The Sound-to-Speech Translation Utilizing Graphic Symbols (STS/Graphics) system is a voice recognition computer-based system designed to allow individuals with mental retardation and/or severe physical disabilities to communicate with others and to control their environment. Operation of the STS/Graphics system is through speech/vocalizations, switch activation, or keyboard input for activation of electrical appliances and/or digitized speech output. Customized photographic quality symbols representing familiar items in the user's environment are displayed on the monitor for the user's choice making. Choices for communication or environmental control are made through direct selection, linear scanning, or row/column scanning. Assessment and educational applications are additional uses of the system. Research on the STS/Graphics system was conducted with students in a local public school system.

## Background

There are more than two million children and adults in the United States whose physical and/or mental limitations are so severe that they are unable to communicate with other persons or interact with and learn from their environment in an effective manner (Bricker & Filler, 1985). Over the past five years, voice recognition technology has advanced to the point where it now represents a viable, and even quite versatile, means of alternate access to education and habilitation for persons with severe handicaps. Speech is the most natural way to communicate and to act on the environment. Therefore, it is also a natural means by which to empower an individual. Computer technology, configured with voice-recognition access for communication and environmental control output, has the potential to effectively compensate for the limitations imposed by mental retardation and/or physical limitations. The Sound-to-Speech Translation Utilizing Graphic Symbols (STS/Graphics) system investigated the use of speech technology for communication and environmental control.

The STS/Graphics system is a voice recognition computer-based system designed to allow individuals with mental retardation and/or severe physical handicaps to communicate with others and to control their environment. This includes individuals with quadriplegia, spinal cord injury, cerebral palsy, aging problems, arthritis, and assorted neurological disorders. Operation of the system is through speech/vocalizations, switch activation, or keyboard input for operation of electrical appliances and/or digitized speech output. Customized photographic-quality symbols representing available choices are displayed on the monitor for the user. The choices for communication or environmental control are selectable through direct selection, linear scanning, or row/column scanning. Assessment and educational applications are other uses of the system.

The main features of the system are as follows:

*Voice Input*. The system incorporates the Votan 2000 voice recognition circuit board and software routines. Each user can store voice templates for sets of up to 64 messages, consisting of sounds or word phrases of up to 8 seconds each in duration. Multiple users can simultaneously store templates for their messages and access them. For individuals for whom consistent sound production is not possible, the system can be adapted to accept a simple vocalization as a means of selecting desired items via a visual scanning routine.

*Sound-to-Speech Translation and Expansion*. The system incorporates an algorithm that translates any designated sound input, whether intelligible or not, into a specified speech output. For example, if a user's vocalization for water approximates "wuh" and s/he only speaks in single-syllable vocalizations, the system can immediately output "Could I have a drink of water, please." The output is digitized speech which can be up to 8 seconds in duration, thus permitting single words or complete sentences to be output.

*Environmental Control*. The system incorporates X-10 technology. Any voice (or other) input can be linked to the activation and deactivation of any electrical device. A single voice input can be linked to any combination of spoken outputs and device activations.

*Universal Controller*. The system uses a One-for-All universal controller which can control any audio/visual device that operates with the use of an infra remote controller.

*Graphics System Interface*. The system generates photographic-quality images of items, appliances, or people in the user's environment

In addition, the size of the image as well as the number of images appearing on the display, can be customized to the user. This is achieved by digitally scanning the images into the computer. For example, a photograph of a tape player might be configured to produce the message "I like this music" as well as activating the tape recorder to play music. Displays can be created of varying sizes ranging from a 2 x 2 to a 5 x 5 matrix. The graphics display can "flip" to a second page of choices as well.

The STS/Graphics software provides two methods of accessing the system: direct selection, and scanning. In the direct select mode, a user produces different sounds, each of which is matched to a picture that may be included in a single or multi-picture display. A set of sounds can be "trained" in the system and stored for each potential user. A picture can be associated with different utterances for each user. Thus, the system is customized for each person who uses it. Scanning can be operated two ways: linear scanning or row-column scanning. In either scan mode, the system requires only a single vocalization, and it is not necessary for this sound to be very consistently pronounced from one instance to the next. This vocalization is used to halt the scan routine. Once the scan is halted, the functions that are associated with the cell on which the scan stopped are executed: that is, speech output, environmental control, or both.

Photo libraries are created for the users. A library consists of disks containing scanned images of items which have personal meaning to the user. The library is arranged by category and may serve as a good organizational model for the users. In this way, images may be used for a variety of subjects in their displays.

*Software Design*. The software package is made up of three major components: Speech Manager, Setup, and Sound-to-Speech. Speech Manager provides the audio recording and vocabulary training functions for the speech recognition board. Speech Manager processes and stores the utterances or words that are used as a trigger or switch by the software. For use in the Direct Selection method of access, the vocabulary trainings are matched to an individual picture. In the Scanning access method, only one sound training is in the system. The Setup section of the software is used to combine picture files, audio output messages, and environmental control commands into specific cells in a matrix. When all of the required cells in a matrix are filled, then the information is stored as a "page" file. Sound-to-Speech executes any of the pages created by Setup and generates activity reports regarding the operation of the software

*Reports*. The system generates activity reports regarding the operation of the software. As each cell is activated, the actions corresponding to that cell, such as audio playback and environmental control, are stored in a data file from which reports are derived containing analyses of these activities.

Research Questions

The following research questions were addressed in this study: Can the subject learn the cause/effect relationship between vocalization and function? Can the subject learn that different vocalizations are associated with different functions? Will the subject exhibit increased communication wi h others? Is there a degree of mental retardation that excludes a user from effective operation of this device? Is the graphics component a viable option for this type of communication/environmental control device? What are the strengths and limitations of the system?

Method

The hardware used in this study were a PC/AT microcomputer, a Votan VPC 2000 Speech Card and Speech Recognizer, a VGA Color Monitor, a Color Scanner, and a Mouse. The software was customized according to the earlier description.

*Subjects*. Twenty-four students from the local public schools were evaluated. The characteristics of the six selected subjects were as follows: four females, two males, four ambulatory, two non-ambulatory, ages 7-21, with diagnosis of cerebral palsy, encephalitis, and mild to profound mental retardation. The subjects understood rudimentary scanning, knew cause and effect, and had adequate vision and hearing. Research was completed on three of the subjects. Two were direct selectors and ambulatorypry; one was a scanner and non-ambulatory.

*Procedure*. The STS/Graphics system was used in the school environment of each subject. Prior to the experimental trials, personal items presented on the graphics display were identified using forced choice selection with each subject for communication, environmental control, or a combination of both. Identification of each subject as a direct selector or as a scanner was determined. Operation of the system was integrated with specific training strategies used with the subjects to teach them proper delivery of personal vocalizations for system training and operation as well as for choice making from items on the display. Each subject progressed through specific training steps from selecting a single item on the display to selecting multiple items on the display which were topically similar when presented (i.e., beauty aids). A trial consisted of the researcher prompting the subject to activate a specific device or communication phrase. A trial was deemed successful if the subject emitted the vocalization that corresponded with the device or communication that was prompted, and if the computer system recognized it as such. During single item trials, there was only one graphics icon displayed on the monitor. Over time, additional graphics icons and their corresponding choices were added to the display. The subject would advance from the single item to multiple items based on successfully completing nine out of twelve trials on each level of item displayed.

*Research Design.* A multiple-baseline-across-target-vocalizations experimental design was implemented with all subjects, whereby designated vocalizations resulted in output of a communicated phrase or operation of an electrical device in the environment.

Results

The three subjects, each of whom had different degrees of mental retardation, learned to communicate and to make choices by using their own personal vocalizations to operate the STS/Graphics system. There was variability among the subjects in their level of proficiency in operating the system. All learned the cause/effect relationship between vocalization and action, and also learned that different vocalizations were associated with different functions. The subjects demonstrated increased frequency of vocalization and speech usage outside the research environment. The graphics component of the system was versatile and appropriate in this application.

Discussion

The STS/Graphics system is a viable method for communication and environmental control by persons having mental retardation and/or other physical disabilities. Limitations of the STS/Graphics system were the microphone placement demands, additional training of the system due to subjects improved vocalization, noisy environments, and a lack of portability of the system. Additional applications of this system for evaluation, training, and education should be explored. The system was effective in encouraging persons with mental retardation to use their natural speech to communicate and to control their environment. Further research on voice recognition for persons with mental retardation should be conducted.

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A documentary videotape of this research, *Voices of the Future*, is available from The Arc. A detailed operations and training manual accompanies the Sound-to-Speech/Graphics system.

Carrie Brown, PhD, Director
Bioengineering Program
The Arc
500 East Border, Suite 300
Arlington, TX 76010

# STRATEGIES FOR TESTING AND DEBUGGING ELECTRONIC COMMUNCATION DEVICES

David H. Hershberger
Prentke Romich Co., Wooster, Ohio

## ABSTRACT

Testing and debugging equipment is a concern of all manufacturers of electronic equipment. Because of the importance to users, proper testing of electronic communication aids is especially critical. This paper outlines some of the techniques that we used to test and debug our latest communication aid. The strategies that are discussed are beta testing, environmental testing and automated testing.

## BACKGROUND

Communication Devices, even more than other electronic devices, must be designed to withstand the daily use which is expected from them. When a consumer device malfunctions, its often an inconvenience. When a communication aid malfunctions, however, the user must rely on some less efficient means of communication, at least until a replacement device can be sent from the factory. Paradoxically, communication aids are frequently used in more hostile environments than similar consumer equipment. Most computers are intended to be placed on a desk and seldom, if ever, moved. Communication aids, on the other hand, are transported on school buses, taken out in the rain and bounced around on wheelchairs. Therefore, although communication aids are often used in harsher environments than similar consumer devices, it is more critical that they continue to function properly.

## STATEMENT OF THE PROBLEM

Several issues are important in making sure that a newly designed communication aid is ready to go to market or even to be used by a number of people in a clinical setting. These design issues can be divided into two broad categories. The first category deals with the device as an embodiment of concepts. When the product definition is initially prepared, the device often only exists on paper and in the minds of the designers. Therefore, some of the features which seemed wonderful at the point of product definition do not work very well when actually implemented into a real product. This means that even when a product is designed to specification, it may fall short of its intended purpose because of real life issues that could not be anticipated when the definition was prepared. Furthermore, after the initial concepts have been implemented into a real device, it is often apparent that slight modifications and enhancements would greatly enhance its utility. Issues which fall under this initial category of questions are:

- Does the communication aid live up to its project goals?
- What modification could be made to make it easier to use?
- Are the prompts and instructions clear enough so that they are easily understood?
- Are there additional features which can be added to the device to increase its functionality.

The second group of concerns deal with a device's use in a real life situation. While a product is in development, it is subjected to an artificial environment. The engineers who use the device know how it is supposed to work, and therefore use it accordingly. The device is comfortably sitting on a workbench in a laboratory as opposed to bouncing around on a wheelchair. So although a product may appear to be completely developed, there are often a number of questions.

- Does it meet its product specification?
- Do all functions work in all situations?
- Is the software completely debugged?
- Will it withstand the environment in which it is normally used?
- What if it falls off of the wheelchair?
- What if the user pushes the wrong buttons?

## APPROACH

Several approaches were used to answer the various questioned presented above. In *beta testing*, a prototype device is given to a user. This helps to evaluate how a new user responds to the device. The purpose of *environmental testing* is to make sure that the device will withstand the environment in which it will typically be used. Finally, *automated testing* is employed to do testing which is either too tedious or time consuming to be done by individuals or in cases where a more random style of pressing keys is desired. Each of these methods is described below.

**Beta Testing** - Once a product has gone through its initial development phase, it becomes crucial that true users get their hands on it. The choice of which users to involve and when to bring them into the development process needs to be given careful consideration. On the one hand, it is desirable to have the unit beta tested as early in the process as possible so that if there are serious problems with the user interface, they can be resolved before becoming even more imbedded into the product. On the other hand, beta devices are destined to 'crash'; creating frustration for the user. Some people take beta testing as a personal challenge and as their chance to have an impact on the development of project and can take periodic crashes in stride. Other users are less tolerant of a device in which they cannot place 100% confidence. The users who are involved should be well informed of what they can expect of the devices and what is expected from them as feedback.

Beta testers should be encouraged to relate all of their impressions and problems to the designers. The designer, though, needs to exercise care in implementing changes which are suggested by the users. That which may make a device easier to operate for one person, may make it more difficult for the next user. A broad variation in the beta testers can help to eliminate and evaluate such feedback. Furthermore, for maintaining reasonable time schedules, the designers should be careful not to let the product definition change too much. In our case, we were writing the user manual in parallel with the product development. Sometimes a few lines of code in the software could change many pages in the manual.

In spite of all these issues, we cannot overemphasize the value that beta testing has made in our particular project. We have discovered where instructions were unclear to the first-time user. We have found cases where the device crashed when the user did something that we didn't expect them to do. We have also obtained some very helpful information on how we can improve the system to make it more powerful and easier to use.

**Environmental Testing** - Environmental testing can actually be a rather enjoyable experience for the design team, especially on projects that have taken much time and created periodic frustration. This is where the device can be knocked off wheelchairs, kicked down a flight of stairs and generally abused. This step is important for two reasons. First, it makes evident those parts which are most vulnerable to damage so that they can be improved. Second, it helps to create guidelines and limits which can be communicated to users.

In our project we kept a careful log of what action we performed and the damage which resulted. This proved very valuable for making changes such as choosing alternate mounting hardware where components were more subject to jarring and vibration.

**Automated Testing** - As important as human involvement is during the testing procedure, it does have its limits, especially in debugging the software. For one thing, the more users become familiar with the device, the more likely they are to use the device exactly as it was intended to be used. During the later stages of debugging, the device typically works fine when it is operated the way the engineers expect it to be operated. It is during those times when the user makes a mistake or tries to do something that the designer did not anticipate when 'bugs' are found. The more sophisticated a device, the greater the number of variations and mistakes that can be envisioned. A second limitation on user evaluation is that the user can only press so many keys during a given period.

This discussion leads to the concept of automated testing through random key generation. Typically at this point in the project, the general operation has been tested thoroughly, but the next concern is verifying that when the user does something that is not expected, the system is robust enough that this will not cause unexpected consequences. Taken to its extreme, one can imagine the user pressing any sequence of random keys and functions. In random key generation, that is exactly what takes place. However, the device itself is programmed to generate the random keys rather than having it be done by a user. In this way a number of devices can simultaneously be testing themselves with each one generating many key activations per minute.

Random key generation is actually more involved than it sounds initially. Although the key generation needs to be random, it also needs to be repeatable. Otherwise, if an error is detected, it is impossible to reenact the action that caused the malfunction. It is impractical to log each key activation as it occurs because the error may not happen for several hundred thousand key activations. Not only is this approach cumbersome, but it also increases the chance of creating a testing situation which is substantially different from the way the device is operated in normal use. Our approach was to develop an algorithm for generating key activations which are dependent on a six-digit decimal number, called the seed. Thus by reinitiating the test with the same seed, the same sequence of keys will be activated.

Sometimes it is preferable to modify the generation routines to generate key activations by rules rather than by pure chance. For example, if the engineer feels that the device is more vulnerable to malfunction when a message is stored than when the message is spoken, he can modify the routine so that the 'program' key has a greater chance of being activated than the 'speak' key. In addition, certain device parameters can be changed to make the testing either more efficient or at least more bearable. It turns out that twenty units generating key activations and accompanied by beeps, speaking and printing can be quite irritating when they are next to you in an office. So we simply made sure that we could disable these features when it was in the random key generation mode.

The tested device needs to be able to determine when an error has occurred. It also needs to be able to report the error to the engineer and be able to replicate the problem. In our system we had a number of error detection routines built into the software already. These detection routines determine such things as bus and address errors, overwritten buffers, and time-out conditions. These conditions are also the type of errors that need to be detected in random key generation. We simply made use of the existing routines and detected when the device either made and error or was about to make an error and then had the device generate a print-out which gave information as to what type of error occurred, what routine the device was in, and how many keys had been activated before the error occurred.

With the help of the original seed, the error report and an in-circuit emulator, we were able to duplicate a malfunction, catch it in the act and repair the problem. For instance if an error occurred after 76,120 key activations, we could have the unit duplicate the first 76,000 activations and then stop. We could then single-step through the remaining activations and watch was happening internally in the device on the in-circuit emulator.

## RESULTS

The popular theory which states that no complex piece of software is ever completely debugged probably still holds true. However, there are definite steps that can be taken to make sure that a device is tested and debugged as much as possible before individuals depend on it for communication. The more sophisticated a piece of equipment, the more critical it is that a formal approach is taken to make sure that the device is ready for market. Further, the more an individual depends on a piece of equipment, the more critical it is that the equipment continues to function without failing.

We have implemented each of these testing strategies on our latest commercial product. The beta testers who worked with us were very cooperative. They used the devices full-time, they let us know what they liked about the device and what they didn't like, and they were very patient with early versions of the system which still had many problems to be worked out. In return, we made every effort to respond to each question and problem immediately. In the end we have a better product and they feel good about helping to develop it.

The random key generation system which we implemented generated approximately 2500 key activations per minute, or between one and two million key hits per day. Initially, problems surfaced in minutes, later it took hours and then days before we found a problem. This device is now on the market and since its introduction, we have been quite satisfied with its performance in the field. We plan to continue and refine these methods of testing.

## ACKNOWLEDGMENTS

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David H. Hershberger
Director of Research and Development
Prentke Romich Co.
1022 Heyl Rd., Wooster, OH 44691

# A COMPUTER PROGRAM FOR MYOELECTRIC CONTROL ASSESSMENT

Anne-Caroline Dupont & Evelyn L. Morin
Department of Electrical Engineering
Queen's University at Kingston
Kingston, Ontario, Canada

## ABSTRACT

A computer assessment program for myoelectric control of artificial hands has been developed to help therapists identify the major control problems of amputees using myoelectric artificial hands. The program uses the display of a hand on the screen as a prosthesis representation. The amputee has 12 tasks to perform with this prosthesis display and the therapist has access to all the data concerning the control of the prosthesis by the amputee.

## BACKGROUND

It is estimated that 1 child out of 4200 is born with a congenital upper-limb deficiency; the number of congenital upper-limb deficiencies for which prosthetic treatment is appropriate is estimated as 1:9400 live births (1). These children are normally fitted with a passive prosthesis at 6 months and may be fitted with a two-function myoelectric prosthesis between the age of 2 1/2 and 4 years (2, 3). The Hugh MacMillan Rehabilitation Centre in Toronto has a total of 287 clients on file in the Powered Upper Extremity Prosthetics Programme. Of these, 126 are under 16 and 58 are under 6 years of age. In 1990, 112 patients were fitted at the clinic (4).

## OBJECTIVES

Therapists who are following children fitted with myoelectric arm prostheses report being able to assess only very gross improvement in prosthesis control due to the difficulty of detecting the exact commands that the patients send to the prosthesis (5, 6, 7). Since most of the commands are very short in duration (the hand can go from fully closed to fully opened in one second or less (8, 9, 10) ), the human eye cannot follow all motions described by the prosthesis. It would be useful for the therapist to know the exact movements requested of the prosthesis in order to assess how well a patient is able to control his\her prosthesis and if functional control is improving over time. The therapist can then adjust the exercises given to the patient so that the movements with which he or she has the most difficulties can be improved.

## STATEMENT OF THE PROBLEM

It was decided to develop a computer-based assessment program for amputees fitted with a two-function prosthesis,which would record with precision the patient's myoelectric response to a displayed task. The program would also store patient information and keep an on-going record of the patient's performance.

## DESIGN

The assessment program was designed to meet the following requirements:

- the patient is to be wearing the prosthesis socket at the time of the evaluation because the socket will provide the confinement that the patient experiences when wearing his\her prosthesis and the electrodes will be correctly positioned.
- computer graphics display is to be used for visual feedback and should respond in the same manner as the prosthetic hand to the electric control signals that the amputee selects.
- the tasks that are demanded of the amputee must be displayed in a clear and non-confusing manner on the screen.
- the information recorded during the evaluation is to include all movements (open, close), rest period and cocontractions and is to be filed and examined at a later time.
- the assessment program must be motivating for children as young as 3 and 4 years old whose attention span is limited.

## DEVELOPMENT

During the evaluation, the patient wears his\her prosthesis with the hand removed; the signal from the prosthesis control unit to the hand motor is input to the computer's serial port via an interface box. It is important that there is no modification of the computer so that the cost of the system is minimized, making it affordable to a large number of hospitals and rehabilitation centres.

The visual display was chosen to be an animated hand so that the child could relate to the function of his\her prosthesis. The hand can be positioned in 20 pre-defined positions and the right hand or the left hand may be selected.

A mirror image of the animated hand in a selected target position is used to demand a task of the amputee (Fig. 1).

Every time the child reaches the required position with the animated hand, a reward consisting of an attractive image and a short melody is offered. This encourages the child to continue the assessment program and gives him\her a sense of accomplishment. Three levels of difficulty are available in order to keep the assessment program challenging for the child.

The program is menu driven to facilitate use by a therapist. Four main options are given to the therapist at the beginning of the program:
- demonstration of the program
- evaluation of a new patient
- repeat evaluation of a patient
- viewing patient's results

The therapist also chooses the level of difficulty and an exit option is available many times during the program (Fig. 2).

## EVALUATION

The assessment program is working and is ready to be clinically evaluated. It is felt that occupational therapists are the most qualified to perform an objective evaluation and the program will be sent to 3 different centres for evaluation and modification.

## CONCLUSION

This program was initially designed to detect control problems of young myoelectric hand users and to assess improvement of prosthesis control with time and training. It could also be used as a training device, if it were presented in a game form with more attractive rewards and a scoring system.

This program fills a need in the prosthetic clinic, where previously therapists had no objective method of myoelectric control assessment.

## ACKNOWLEDGEMENTS

Funding for this project is provided by NSERC Operating grant #0042545.

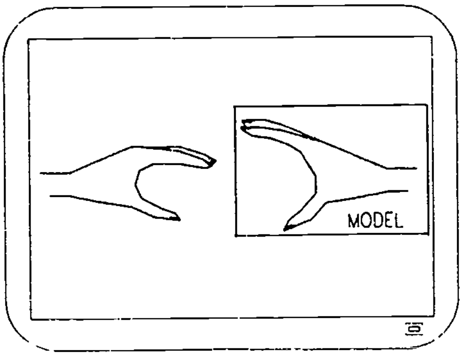


Fig. 1: Visual display

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Anne-Caroline Dupont
Department of Electrical Engineering
Walter Light Hall
Queen's University
Kingston, Ontario, Canada
K7L 3N6

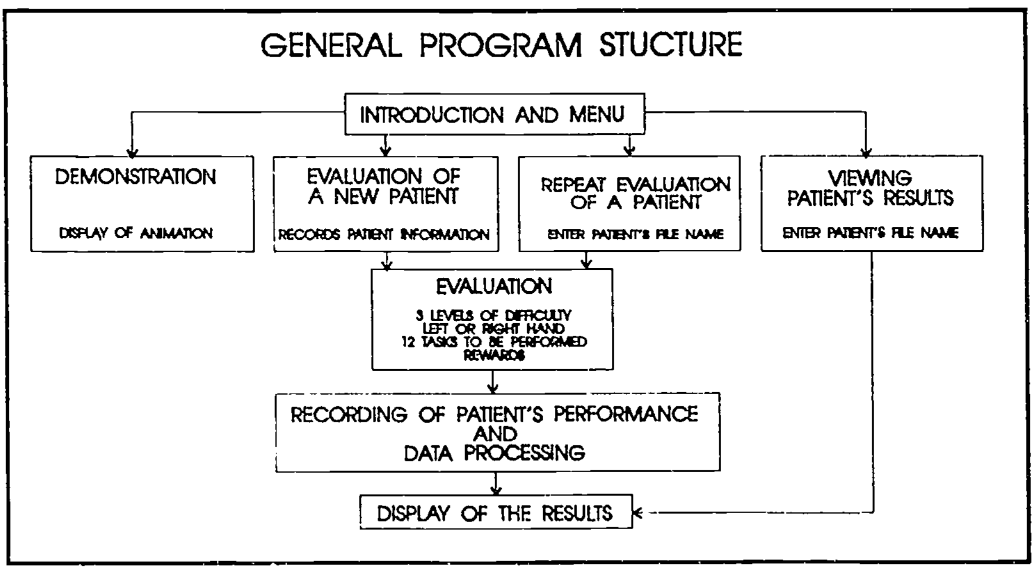


Fig. 2: General program structure

# DEVELOPMENT OF THE THERABOT[R]: AN EVALUATION, EXERCISE, AND RESEARCH TOOL FOR REHABILITATION THERAPY

Katherine A. Kristy and Clive R. Taylor
Therabotics, Inc.

## Abstract

The Therabot[R] is being developed to be used in the rehabilitation of physically disabled individuals. It addresses the needs of physical rehabilitation specialists by providing an evaluation tool, an exercise modality, and a research tool. The Therabot[R] is an integrated system consisting of a robotic arm, data acquisition system, task components, and sophisticated software.

The development of this system is significant in that it satisfies requirements for providing physical rehabilitation to patients who have a vast array of physical ailments including or resulting from cerebral vascular accident, burns, multiple sclerosis, arthritis, prosthetic use, and cerebral palsy.

## Introduction

The system is being designed for upper extremity therapy and research encompassing activities of coordination, range of motion, quality of motion, strength, and endurance.

Patients will interact with the system by following the motion of the robot with their affected limb, apply force to the robot or resist forces of the robot, and manipulating objects of various shapes.

The therapist determines the appropriate activities to be performed, the length of the sessions, and the movement pattern of the robot. This allows the therapist to customize the activities to meet the individual needs of each patient.

The system measures various parameters including force exerted by the patient, quality of motion, range of motion, time to complete activities, and the number of repetitions successfully completed.

The system provides feedback to the patients as they are interacting with the system. This feedback is auditory, visual, and tactile depending on the needs of the patient. A report of the patients' progress is provided for the therapist and/or researcher. These reports can be used for analysis and further activity planning.

## Background

The development of the Therabot[R] is a significant enhancement to the work conducted on the Robotic Exercise System (RES) described in Kristy [1]. The RES is a pilot system developed for purposes of evaluating the acceptance of the concept, that is, the use of a system which includes a robot arm, in the rehabilitation process. The Therabot[R] is a new system, which builds upon the RES concept.

## Discussion

The development of the Therabot[R], which is currently in progress, consists of designing a robot that is suitable for this application, writing software, and developing the interactive devices.

The robot will have state-of-the-art safety features, and have a work envelope that is suitable for therapeutic activities. The software will control the robot's movements and record the patients' responses and performance. The devices which the patients interact with to perform the activities are being developed.

The activities performed with the system and the feedback provided by the system will not be able to replace the therapists' responsiveness to the patients' progress. The system is being designed for therapists and researchers to use as an additional tool in the therapeutic process.

1. This system is designed to be used as a standardized evaluation tool to determine functional assessment.

   The issue of functional assessment is essential due to the fact that rehabilitation specialists are being required to provide objective data indicating a patient's functional outcome and progress [2].

   Since the system is able to measure range of motion, quality of motion, and is reliable in terms of accuracy, speed, and repetition, it can be used as a standard evaluation tool.

2. The system is an effective therapeutic modality providing customized activities based on individual patient requirements.

   The system simulates activities currently used in the physical rehabilitation process. The system precisely measures and guides the motion of the patients' limbs. This will allow repetitive exercises to be developed by the therapist meeting the therapeutic requirements of each patient. The exercise task components allow for a vast array of motions, grasping and prehension patterns, and strength and endurance activities. These components include push buttons, knobs, and other interactive devices.

3. The versatility of the system makes it a valuable research tool.

   Rehabilitation units are facing problems of scarce resources. In order to facilitate the resources available, length of stay (LOS) predictions, and patient functional outcome would be beneficial.
   The system can be used to collect data on patient progress, from initial assessment up to discharge, so that it may be analyzed to formulate predictions for length of stay.

   It is also useful in determining the effectiveness of particular exercise activities for the varying patient populations.

The system is innovative. It has the capability of being an effective tool in the rehabilitation process. The system does not meet every need of every patient. For example, patients just beginning rehabilitation after suffering a stroke, probably will not benefit from the system. These patients will most likely benefit from the system as progress is made in recovery. The applications to the various diagnostic groups will be determined during further design, development, and evaluation phases.

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Kathy Kristy
Therabotics, Inc.
2727 Second Avenue
Detroit, MI 48201

# Design and Testing of Four Underarm Crutches

Maurice A. LeBlanc, MSME, CP, Lawrence E. Carlson, D. Eng.,
Teresa Nauenberg, BSME
Packard Children's Hospital REC

## Abstract

This article reports on a project to design, build and test four different designs of crutches to determine if they offer promise for more efficient gait for users. Results from testing with five disabled and five normal subjects showed that the suspension crutch was the most energy efficient and has promise but that none showed statistically significant energy savings.

## Background

Crutches have not changed significantly over 5000 years of use(1). There are many reasons - physiological and psychological - why it is good to stand and walk rather than sit and have wheeled mobility (2). However, it takes roughly twice as much energy for a person with paraplegia to walk with crutches than an able-bodied person to walk normally (3).

## Research Question

This project was undertaken to look at the feasibility of different designs of crutches to lower the high energy cost of crutch gait and thereby make the use of crutches a better option than the use of wheelchairs, which are more expensive, have physiological and psychological disadvantages, and are more architectually restrictive.

## Method

Design and Construction (See Fig. 1-4)

The roller or rocker crutch was put forth by Joll in 1917 (4) and by Hall in 1918 (5). Lumex, Inc.(6) currently makes the Sure-Gait Axillary Crutch which has a small roller bottom the same width as the double uprights. The concept is that the arc is a segment of a circle with the center at the shoulder so that the shoulder stays more level in walking and that the stride length is increased by the length of the rocker.

The spring or pogo crutch was described by Lewin in 1928 (7) and by Shoup in 1980 (8). The concept is that it absorbs shock at ground contact and gives energy return at push off.

The saddle or suspension crutch was introduced by Taylor in 1883 (9). The saddle or harness is connected to suspenders which extend to the crutch axilla pads, thus allowing a person to bear weight on the perineal area rather than the arms. It is relatively light in weight and uses standard axillary crutches.

The prosthetic foot crutch was proposed by LeBlanc. The concept is to have a crutch that "walks". An energy storing prosthetic foot is used at the bottom of the crutch. The action of this crutch is like the roller/rocker crutch in that it provides greater stride length and like the spring/pogo crutch in that it has springiness.

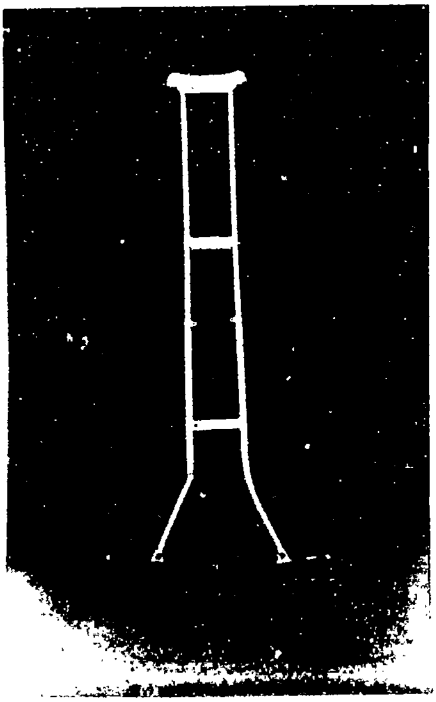

Fig. 1. Roller or Rocker Crutch

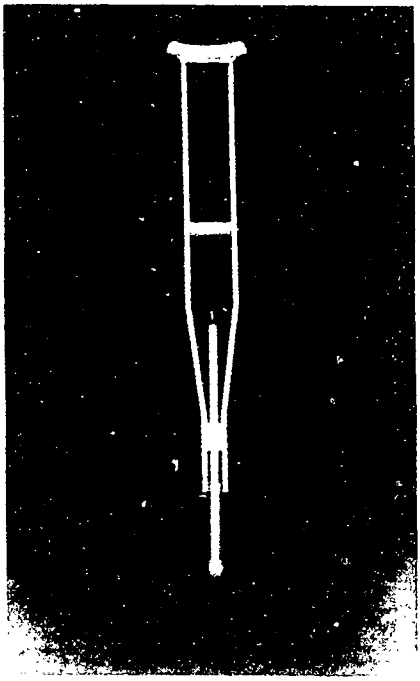

Fig. 2. Spring or Pogo Crutch

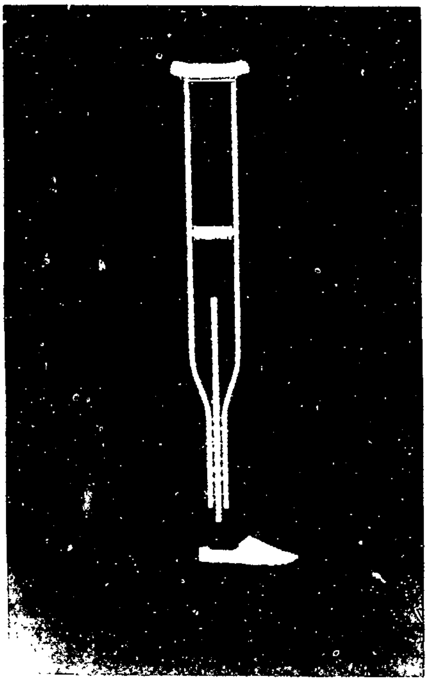

Fig. 4. Prosthetic Foot Crutch

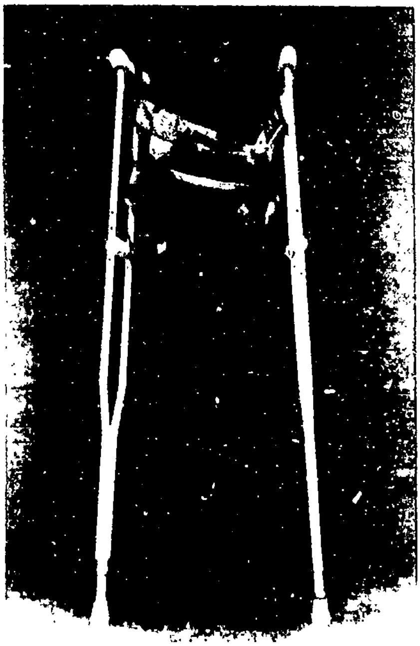

Fig. 3. Saddle or Suspension Crutch

## Testing

Five regular crutch users and five normal subjects were tested using the four experimental crutches versus standard underarm crutches in swing-through gait by walking around an indoor oval track at self-selected comfortable speeds. The Energy Expenditure Index,EEI (10) and average velocity for several runs for each subject and each crutch were taken. Data was recorded and analyzed using the Student t-test, paired t-test and t-test for independent means.

## Results

Results indicated that the suspension crutch was the lowest in energy expenditure. However, none of the four experimental designs showed statistically significant improvement in energy expenditure versus the standard underarm crutches currently in use.

## Discussion

The suspension crutch is the most novel of the four designs and received the preponderance of positive comments from the test subjects. It was perceived to give weight relief but also felt slower and less stable. One subject summarized it as requiring the most skill but the least effort. Based on the objective and subjective test results, it is the opinion of the authors that the suspension crutch has potential and merits further research.

## Acknowledgments

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Maurice A. LeBlanc, MSME, CP
REC Director of Research
Packard Children's Hospital
725 Welch Rd.
Palo Alto, CA 94304
(415) 497-8192
FAX (415) 497-81

# Description of Video Programming for the Blind Audience -- How It Is Done and How It Is Delivered to the Consumer

William A. Gerrey
The Smith-Kettlewell Eye Research Institute
San Francisco, California

Abstract

The adoption by the FCC of an industry standard for "Multichannel Television Sound" (MTS), together with satellite distribution of programs from the network to station affiliates, means that specially described versions of TV programs can be delivered to the blind consumer via off-the-shelf station equipment and television sets. All stages in creation and service delivery are addressed: writing the description, narration, preparation of the special videotape to be aired (or to be distributed in VCR format), network distribution, and ultimately, transmission and reception via the "Second Audio Program" (SAP) subcarrier. A comparison is made with "closed captioning" for the hearing impaired.

Based on a technical viability study undertaken by the author for OSERS, the present paper summarizes the state of the art in this technology.

## Problem and Background

Before mechanisms emerged by which special audio channels could be dedicated for use by the blind and visually impaired (adding subcarriers to the signals of broadcast stations), blind TV "viewers" had to rely on family and friends to fill in missing information presented visually. In 1981, soon after "radio reading services" were installed in major cities (using the 67kHz subcarrier of FM broadcast stations), the Washington Ear radio reading service undertook a pilot project of describing a few programs of the Public Broadcasting Service (PBS).[1]

The disadvantage of using radio reading services is that there is usually only one per service area; newspaper and magazine reading would be preëmpted by each described program.

In 1984, the Federal Communications Commission (FCC) adopted, as "a protected standard," a protocol for "multichannel television sound" (MTS). Not only does this system accommodate stereo audio, but a "second audio program" (SAP) subcarrier is also defined.

Since 1990, PBS has been distributing, through its network, a selection of programs carrying a mixture of the original program sound track and a narrated audio description over a separate audio channel. While radio reading services have been known to transmit this audio, the primary delivery to the blind consumer has been via the "SAP" subcarrier of affiliated TV stations who have that capability.

The emergence of home videotape has become another delivery system. Specially prepared video cassettes bearing description are available from at least three sources.

## Method/Approach

The description of video action is read by a narrator using "narration to picture" techniques normally employed in making documentaries. The narrator reads from a printed script containing timing information and other cues. Timing is important so that descriptive phrases can fit between passages of dialogue on the program sound track. The script, printed with time-code information in the margin, can be created in two ways:

(1) A so-called "burned-in window dub" of the videotape can be made at any video production laboratory; this shows timing information on the screen. Using this "dub," and with the aid of a hand-held time-code calculator, a description script can be typed or handwritten. This system has no flexibility, however; if the time code is shifted by insertion of announcements and/or late program changes, the time-code numbers noted in the margin will be incorrect.

(2) Computerized editing stations with synchronous tape machines can be used. These have a so-called "tape logging feature" (used for making detailed tape labels) which gives the writer a basic word processor and the ability to print a script with automatic assignment of time-code numbers. Where even minor changes render previous time-code information obsolete, these editing stations allow automatic reassignment of timing information which can be reprinted at the last minute.

WGBH-TV, Boston, has assembled a customized script-writing setup which they use for their Descriptive Video Service (DVS, a registered service mark). Thus, a costly editing station is not underutilized by a description writer who is only interested in the tape logging feature; in addition, their system has features of particular utility for creating the script. For example, the speech rate of the narrator can be entered into the computer. Then, if a descriptive phrase is too long to fit into a selected silent passage, the computer informs the writer of this fact, and can be called upon to read that phrase in synthetic speech to show the writer what it would sound like if it were narrated fast enough to fit in.

Synchronous audio and video tape machines are now commonplace, and these play an essential role in synchronizing and mixing the narrative description with the program. The Society of Motion Picture and Television Engineers (SMPTE) has created telemetry systems whereby time-code information can ride either on a low-fidelity audio track, or on "field A" of video lines 16 and 18. Thus, a narrated master audio tape of the program is automatically synchronized with the video program, and a new track containing this special sound track is recorded onto the tape to be aired.

The network must then arrange for an added audio channel to feed the extra sound track to the satellite uplink. For now, there is no shortage of bandwidth for satellite transmission of the added information. Commonly, 27 MHz transponder channels carry a single program, and plug-in modules for adding new audio channels are only a few hundred dollars each.

At the broadcast station, the extra audio must be routed from the satellite downlink to the SAP generator on the transmitter exciter. The addition of SAP is an inexpensive option on modern transmitters.

The SAP subcarrier is a narrow-band FM (10 kHz deviation) signal which, in turn, is made to frequency modulate the main-channel audio carrier of the TV signal. Its center frequency ($f_c = 78.67$ kHz) is 5 times the horizontal sweep rate; the center frequency of the encoded signal and that of the decoder's discriminator are phase-locked to the horizontal sweep.[2]

Being a "protected standard" means that broadcast stations are free to generate subcarriers different from this, but that standard consumer equipment is made to recognize the SAP subcarrier as a standard if its injection deviates the main carrier more than 7.5 kHz, with a maximum of 15 kHz being allowed.[3]

Frequency preëmphasis and dbx noise-reduction are used to optimize the sound quality of the SAP channel. A 10 kHz audio bandwidth can be achieved, and a signal-to-noise ratio of greater than 60 dB can be attained in good reception areas.

Typically, SAP receiving capability is a feature of medium-priced stereo television sets and on higher-priced VCRs. No special modification for blind users is needed on these sets.[4]

## Comparison with Closed Captions for the Hearing Impaired

Comparing the distribution and service delivery of video description with closed-captioning for the hearing impaired brings to light areas where improvements and new innovation can lead to more widespread implementation. For example, once captions for the hearing impaired are written for a program, they are multiplexed into the video signal (using both fields of line 21); captions require no special handling by the broadcasters, and they remain a part of the video signal on home VCR tapes, all the while being transparent to the hearing user.

In contrast, video descriptive audio, as currently implemented, requires special handling by networks and affiliates. Switching routers and audio consoles used in television have no provision for handling this extra audio channel. Routing the signal requires parallel connection of spare signal circuitry; networks have expressed apprehension that such special arrangements would lead to errors in the broadcasts. Finally, home videotapes have no extra tracks on which to record a special audio channel, so adapted programs are not transparent to the sighted user, and description can only be gotten on specially prepared tapes.

## Future Developments

Two emerging technologies hold promise in mitigating these problems:

(1) At the 1990 Convention of the National Association of Broadcasters, a session called "Television Audio" contained papers describing microcontroller-based "audio-follows-video" equipment whose "setups" can be saved on diskettes. The trend toward computerized program handling will eventually lead to the point where the "special arrangements" so feared by broadcasters will soon be reduced to automatic loading of system configurations.[5]

(2) Funded by NIDRR, the Engineering Division of WGBH in Boston is developing a scheme for multiplexing an audio channel into the video signal -- probably encoding it onto three or four unused video lines in the vertical blanking interval. This would achieve true parity with closed-captioning for the hearing impaired.

A decoder for retrieving audio from the video signal could be in the consumer's equipment. Or, a TV station already using SAP for video description could connect the decoder to their SAP generator.

The U.S. system of multichannel television sound has not been adopted in Canada. Therefore, the Canadian Department of Communications has expressed support for the pending WGBH encoding system, and they intend to create inexpensive decoders suitable for visually impaired consumers.

## Conclusion

Given that the aforementioned technologies have made video description realizable and that future transmission techniques will minimize its special handling by broadcasters, consumers may look forward to more accessible programs. However, the impetus for continued effort is driven by the availability of programming. Captioning for the hearing impaired is almost universally broadcast; this no doubt led to the passage, by Congress, of the Television Decoder Circuitry Act (effective in 1993). If described programs exist in quantities that stimulate consumer interest, ways to distribute and deliver them will be optimized to suit consumer demand.

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Acknowledgments

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Author's Address

William A. Gerrey
Rehabilitation Engineering Center
The Smith-Kettlewell Eye Research Institute
2232 Webster Street
San Francisco, CA 94115

# A Fax-Based Reading System for the Blind and Print-Handicapped

William F. Crandall, William A. Gerrey & John A. Brabyn
The Smith-Kettlewell Eye Research Institute, San Francisco

## Abstract

An innovative fax-based reading service allows a print-handicapped client to fax reading material to a remote sighted reader, who will read it back to him over the telephone. It provides convenient, cost-effective and timely print accessibility for the blind, while creating employment opportunities for sighted readers who are individuals with restricted mobility and profit from home-based employment. It also addresses the implementation of the ADA provisions on reasonable employment accommodation (which includes access to print by the visually impaired).

## Statement of Problem

This project addresses a significant need for the blind and visually impaired population -- access to the printed word. In addition to blind and low vision people who may not be able to see the print, stroke, head-injured, or autistic persons may not be able to assimilate printed language on the page. In a typical day, a sighted person routinely opens mail, reads instructions and recipes, deposits checks, reads TV guides, selects audio and video tapes, clips coupons, reads correspondences, invoices and bills, looks at pictures and graphs, and accesses many other forms of print. The blind individual has routine access to few, if any, of these.

The phenomenal growth of facsimile usage in offices is a new and unmet challenge to the print-handicapped office worker. Because facsimile technology is graphical in nature, it is not coded in a manner that allows direct conversion into speech.

## Rationale

All of the above printed materials could be made accessible on demand by the remote human reader system of the type we are developing. We are experimenting with a fax-based remote reading service for the target population through a system in which the blind and print-handicapped person faxes written material to a remote, sighted reader who then reads it back to him over the telephone. The system which has been developed handles <u>any</u> kind of written or graphical information.

Among the provisions of the *Employment* section of the Americans with Disabilities Act is the requirement for reasonable accommodation in the workplace. This law requires "... the provision of qualified <u>readers</u> or interpreters, and other similar accommodations for individuals with disabilities" (Title I, Sec. 101, 9.B). We believe the proposed remote reader system will provide a cost-effective method for employers to meet this requirement for their blind or print-handicapped employees.

## Design

The end point of this study is to provide both government and industry with the information they need to realistically access technology transfer feasibility of this system. Strong emphasis has been given to designing a system which will exploit, rather than be limited by, the important real-world requirements of economy of scale and flexibility in the face of emerging technologies.

The major hardware components are three high-speed, but inexpensive, MS-DOS computers (33 MHz) for the readers. They are configured with high resolution "full page display" monitors and facsimile boards. The fax boards also function as a high-speed modem (9600 baud). Flat-bed fax machines are used by the blind clients to transmit documents to the sighted readers.

A major project design consideration has been its transferability to a real-world, permanent implementation. To promote and demonstrate manageability of a large scale, decentralized system, all functions of the readers' computers are remotely accessible by the system manager. This means that software updating, retrieval of reader statistic files, and trouble-shooting takes place directly from the project office by these high-speed modems and obviates the need for the manager to travel between reader sites.

a. Participants

Because this is a telecommunications project, the mobility impaired "readers" can work from their homes. The service operates daily from 1:00 p.m. to 9:00 p.m., to include parts of the working and leisure periods of the day.

Twenty local and five distant blind recipients and users of fax machines are the initial subjects in the study. These blind consumers present a broad spectrum of reading needs. They use the system for both personal and professional reasons and have extended periods in their day during which other types of reading assistance is not at hand. The local users include a college English teacher, a lawyer whose specialty is legal issues around disabilities, the blind owner of a small business which specializes in high technology augmentation devices for the blind, the president of a blind consumer organization who lives alone, one computer company representative, three blind in-house staff members, and members of a living skills center for the visually handicapped which serves as a residence for fourteen blind students. The recent donation by Allnet Communications Services of toll-free, long-distance access for 10 users has allowed us to also include two blind faculty members of an academy in the Midwest, two owners of businesses specializing in high technology augmentation devices in Oregon and two residents of Southern California.

b. Data Collection

*Individual Transaction Records* for each document received by the reader are entered directly by computer into an on-screen form. This questionnaire captures salient information such as 1) page layout (handwriting, print, or graphics); 2) type of document (categories within personal or business); 3) time to receive and review document; and 4) reader and client comments. The data from these entries are automatically appended to a database resident in the reader's computer. The data file containing these statistics are routinely and automatically copied to the system manager's computer by way of high-speed modem for analysis.

The system manager administers a brief telephone questionnaire to customers and readers each month in order to determine if the remote reader service is living up to customer expectations. This *Monthly Interview* focuses on early identification of problems by exploring such issues as 1) desired daily hours of operation, 2) level of customer confidence in reader's ability, and 3) adequacy and reliability of the equipment.

In addition, the system manager polls each customer by telephone at the end of his/her tenure. This *Exit Questionnaire* will access the more subjective aspects of system usage such as his/her opinions on the system's usefulness, number of hours utilized, suggestions for improvements, comparisons with currently used reading method, and willingness to pay for such a service if necessary. The participants are asked how much visiting reader time they normally normally use, how much it would cost, and how much was potentially saved by use of the fax reader system.

Feedback from users and readers also comes from a *Problems and Suggestions Diary* kept by the readers. The system manager maintains close contact with both readers and users in order to identify problems.

Modifications are made to the experimental remote reading service on an ongoing basis as recommended by the project's Advisory Panel which includes four blind persons from our community.

c. Data Analysis

The data is analyzed to determine the breakdown of usage patterns, hours of peak demand by different classes of users, types of documents read, average transmission delay times, and other user statistics. The data on magnification needs, resolution, font size, etc., is utilized to determine whether system resolution and other hardware characteristics are adequate. The proportion of reading material requiring a flat bed versus a single sheet scanner for employment and home settings, as well as the proportion of handwritten, poor print quality, and other categories of material read are providing additional measures of effectiveness compared with other systems.

Cost-effectiveness of the system is determined based upon average reader time per page read, approximate telephone time cost, ownership costs of synthetic speech reading machines, and data from subjects on the cost and efficiency of visiting reader services they would normally use.

The results of the study to date indicate that many of the reading needs of the blind and print disabled are being met by the present system.

## Future work

Future plans include the development, integration and testing of new technologies which approach as closely as possible the "ideal" remote reader -- one which would function in the same way as having a live reader in the same room as the user.

A second direction for future investigation is Optical Character Recognition (OCR) and speech output. The human reader can visually scan, evaluate, and describe the document quickly so that the blind person can efficiently make a decision as to its disposition (i.e., read completely, read account balance or disregard document). However, OCR might be useful in processing the subject document once disposition of the document -- as accessed by the sighted reader -- has been determined.

## Conclusion

We believe the proposed fax-based remote reading service is an innovative approach to addressing a significant need of the blind and print-handicapped target population. The initial results of the study show that the system answers many of the reading needs of the target population. A major project design consideration has been its transferability to a real-world, permanent implementation. Contacts are under way with the telecommunications industry and service agency professionals to maximize the likelihood that a successful demonstration of this concept will lead to permanent implementation of a reading system which will impact the vocational success, independence, and quality of life of countless blind and print-handicapped individuals. In addition, the project uniquely addresses the implementation of the ADA by providing employers with a convenient, low-cost mechanism for print access for disabled employees.

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## Authors' Address

The Smith-Kettlewell Eye Research Institute
2232 Webster Street
San Francisco, CA. 94115

P1.14

# Computer Assisted Tracking System for Evaluating Speech Understanding in Hearing Impaired Persons

Harry Levitt and James J. Dempsey
City University of New York and Rehabilitation Engineering Center on Technological Aids for Deaf and Hearing Impaired Individuals, The Lexington Center, Jackson Heights, N.Y.

Abstract

A computer based technique for simulating the tracking method for evaluating speech understanding has been developed using a video disc playback system under computer control. Several versions of each sentence in a short story are stored on video disc. The particular version played back at any given stage during the test depends on how well the subject responded to the preceding recording. The technique eliminates the problem of uncontrolled variability between speakers (senders) and reduces test-retest variability for speaker-listener (sender-receiver) pairs.

## Background

A particularly difficult problem in evaluating sensory aids for hearing impairment is evaluating the effectiveness of these devices in improving speech communication. Traditional methods of evaluating speech communication ability use phonetically balanced lists of words or sentences as the basic test material, the measure of performance being the percentage of words identified correctly.

This approach, although useful, does not evaluate how people actually communicate by speech. Normal communication involves an interactive process between the speaker and the listener. If a word, phrase or sentence is misunderstood, then the speaker is likely to repeat what was said, typically using different emphasis or a change in the wording. Listening to prerecorded lists of single words or sentences, as required in traditional methods of testing, is very different from the normal communication process.

An alternative method of evaluation that is finding increasing application is the tracking procedure developed by DeFillipo and Scott (1978). This procedure, which was developed for both training and evaluation, requires that the speaker (referred to, more generally, as the sender since the method is not restricted to speech) produce a sentence or phrase, usually by reading a text. The listener (referred to more generally as the receiver) is required to repeat verbatim what was said. If the receiver repeats the material correctly, the sender proceeds to the next phrase or sentence in the text. If the receiver makes an error, then the sender repeats what is said. How this is done depends on the sender's assessment of the nature of the error. The entire utterance could be repeated in much the same way, or with different emphasis, or only a portion of the utterance might be repeated. The receiver is required to repeat this second version of the utterance and the process is continued until a correct verbatim response is obtained. The metric used to specify relative performance is the number of words repeated back correctly per minute.

The tracking technique provides a much closer approximation to the communication process than traditional testing techniques and, as such, has better face validity in evaluating communication ability. It can also be used as a training technique. The technique is widely used, for example, in training cochlear implant patients to communicate more effectively in face-to-face communication.

A problem with the tracking method is that it is subject to several major sources of variability. The technique has been implemented in different ways by various research and clinical groups; the use of live voice also introduces significant between-sender differences and sender-receiver interactions can vary substantially. For example, Receiver A may obtain a higher tracking score with Sender 1 but not with Sender 2, while Receiver B scores poorly with Sender 1 and relatively well with Sender 2.

## Computer Interactive Tracking Simulation (CATS)

A computer-interactive tracking technique has been developed in order to control the above sources of variability, thereby increasing the sensitivity of the tracking method. The computer implementation requires some modification of the tracking method and is thus referred to as Computer Assisted Tracking Simulation (CATS). In CATS, the sender is replaced by a video disc playback system under computer control. The receiver views a video recording of the test utterance and, as in the conventional tracking method, is required to repeat what was said. If the utterance is repeated back correctly then the video disc player moves onto the next utterance in the sequence. If the receiver makes an error, then one of several other video recordings of the test utterance is played to the receiver. The choice of which video recording to use depends on the nature of the error made by the receiver. For example, if the receiver misses a word towards the end of the test utterance, then a video recording of the latter half of the test utterance would be played; if the receiver made errors throughout the test utterance then a video recording of the entire utterance, articulated more slowly and more precisely, would be played.

A personal computer has been programmed to select the video recording to be played at any given time. The computer requires input information indicating whether the receiver repeated the test utterance correctly and , if not, the nature of the error. This information is currently provided by the tester as the test progresses. Techniques for fully automating the technique using automatic speech recognition are currently being investigated. This application of automatic speech recognition is not as difficult as open ended speech recognition in that the computer knows what the intended utterance is and has only to decide whether the intended utterance was produced correctly and, if not, which words were produced in error.

In order to minimize any variability that might be introduced in the current version of CATS due to variations in the tester's judgement as to the nature of the errors produced by the receiver, the task required of the tester has been made as simple as possible. Two binary decisions are required of the tester, whether or not an error occurred in repeating the first half of the utterance and whether or not an error occurred in repeating the second half of the utterance. Given the above information, the computer can logically determine which video recording should be played on the next trial.

The CATS system has been implemented using an IBM-compatible personal computer controlling a Panasonic video disc player. A set of 10 paragraph-length short stories has been prepared. Each short story consists of 10 sentences. There are roughly 10 recorded versions of each sentence, or portion thereof.

## Experimental Evaluation

Two experiments have been performed. In the first experiment, tracking rates data were obtained using CATS and a live sender. The results showed that tracking rates were higher, on the average, for the live sender but that test-retest variability was significantly lower for the CATS system. More importantly, the problem of between-sender differences was brought under control. An analysis of between-story differences showed that 9 of the 10 sets of video recordings produced tracking rates that did not differ significantly. The one set of video recordings that differed from the others (by a small but statistically significant amount) is now used for training purposes.

The second experiment measured the effect of speech-to-noise ratio on tracking rate for eight normal-hearing listeners. The results are summarized in the table below. As expected, increasing the speech-to-noise ratio produced an increase in tracking rate. The steepness of the function relating tracking rate to speech-to-noise ratio was found to be greater than corresponding data reported for traditional single-word speech tests, and that the sensitivity of the automated version of the tracking method was correspondingly greater.

## Conclusions

The computer Assisted Tracking simulation (CATS) system provides significant advantages over the conventional tracking method in terms of controlling inter-sender differences and other sources of variability.

## Acknowledgements

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Harry Levitt
Speech and Hearing Sciences
The Graduate School & University Center
of The City University of New York
33 West 42nd Street
New York, NY 10036-8099

TABLE 1

Tracking Rate as a Function of Speech-to-Noise Ratio

| | Speech to noise Ratio (dB) | | | |
|---|---|---|---|---|
| | -18 | -12 | -6 | 0 |
| Tracking Rate (WPM) | 12.8 | 17.8 | 25.3 | 30.0 |
| Between Subjects Std Dev. | 7.8 | 8.2 | 11.7 | 6.6 |
| Within Subjects Std Dev. | 2.9 | 5.2 | 4.7 | 8.6 |
| | | | | |
| Log Tracking Rate (log 10 WPM) | 1.07 | 1.22 | 1.38 | 1.47 |
| Between Subjects Std Dev. | 0.24 | 0.20 | 0.23 | 0.11 |
| Within Subjects Std Dev. | 0.11 | 0.14 | 0.08 | 0.14 |

# Measurement of Speech Production Skills in Deaf Children

Karen Youdelman & Harry Levitt
The Lexington Center, Inc., Jackson Heights, NY & City University of New York

## Abstract

A difficult problem facing speech teachers is that of evaluating the speech skills of deaf children. Experience has shown a low level of inter-rater reliability on judgments of speech production ability. Even when specific rating criteria have been delineated, each rater appears to be influenced more by his or her own internal criteria than by those specified. Variability of this type reduces substantially the precision with which the speech skills of deaf students can be evaluated. This paper focuses on the use of objective measurement procedures for speech evaluation.

## Background

Instrumentation for the objective measurement of a range of articulatory and voice source characteristics has been developed and combined in a single computer-based system known as CISTA (Computer Integrated Speech Training Apparatus). This system obtains simultaneous objective measurements of voice pitch, nasalization, intensity, neck vibration, vowels, frication and tongue position during speech production. Several sensors are used. These include a laryngeal transducer, a nasal transducer, an air-flow microphone, and an artificial palate for monitoring tongue placement. The system is computerized and allows the speech teacher to display on a video screen any of the speech parameters being monitored. The parameters may be displayed singly or in combination with other parameters. Digital recordings of the student's speech and associated parameter values can be stored conveniently for purposes of record keeping and future analysis.

The purpose of this study was to compare objective data with the teacher ratings in order to (a) pinpoint the speech features most difficult for the raters to assess, (b) evaluate the parameters that might be responsible for the discrepancy between subjective and objective evaluation procedures, and (c) design a training protocol to reduce the effect of these influences.

## Method

The Fundamental Speech Skills Test (FSST) developed by Levitt, Youdelman, and Head (1990) was used to obtain data on a range of speech skills. These included fundamental aspects of voice production and control as well as a sample of articulation skills. The test battery covered four major sections, voice source, pitch control, suprasegmentals, and spontaneous speech. Speech production skills were assessed in a variety of phonetic and phonologic environments including vowels, syllables, words, phrases, and spontaneous speaking situations.

The FSST was administered to 23 severely-to-profoundly hearing-impaired students (8-18 years old). FSST administration was conducted by the student's regular speech teacher. As each item was produced, CISTA monitored all of the sensors noted above. The objective measurements were stored on floppy disks for a total of 52 disk files per student. The teacher's subjective ratings were recorded simultaneously on the FSST test form. Four sets of data were obtained for each test item, two consecutive ratings by the student's speech teacher, one rating by an independent observer, and the objective measurements obtained by CISTA.

The above procedure allowed for data analysis from several different perspectives: (a) inter-rater agreement, (b) the consistency of the student's speech productions on an item-by-item basis, and (c) the relationship between objective and subjective evaluation measures.

Results

Preliminary analyses have revealed that the teachers were quite consistent (>91% agreement) when evaluating the appropriateness of average voice pitch (for age and gender), and the number of syllables produced in words and phrases (>95% agreement), but showed some variability when assessing breath stream control in consonant-vowel environments (<70% agreement) and suprasegmentals including syllable accent (<77% agreement), word stress (<77% agreement), and intonation contours (<67% agreement). The physical measurements obtained with CISTA were, as expected, highly repeatable (close to 100%). This allowed for precise evaluations of the student's consistency. The correlation between objective data and the subjective ratings are currently being evaluated. Good agreement has been found so far on gross pitch characteristics and syllable number.

Several interesting observations were made during the testing. A number of students improved noticeably in their productions from the first to second trial. These students were noted to self-correct and used the speech training system as a reinforcer. For example, the final /sh/ in the word "fish" became more refined over subsequent trials as the student cued into the feedback from the visual display. In addition, the visual feedback encouraged certain students to vary their voice pitches to mark word stress and/or intonation contours. These observations support the contention that CISTA has potential as a self-monitoring tool.

Summary

A comprehensive body of objective data and subjective ratings of speech production skills in hearing-impaired children has been obtained. Preliminary analyses indicate that objective measures can be used to supplement subjective ratings that are prone to high inter-rater variability, thereby greatly improving the precision with which the speech of hearing-impaired students can be evaluated.

Acknowledgement

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Karen Youdelman, Ed.D.
The Lexington Center, Inc.
30th Avenue & 75th Street
Jackson Heights, NY 11370

# PREVENTION OF GLENOHUMERAL SHOULDER SUBLUXATION IN STROKE PATIENTS USING FUNCTIONAL ELECTRICAL STIMULATION

Pouran D. Faghri, Mary M. Rodgers, Roger M. Glaser, John G. Bors, Charles Ho, and Pani Akuthota

Institute for Rehabilitation Research and Medicine, Wright State University; Rehabilitation Institute of Ohio, Miami Valley Hospital; and Veteran Affairs Medical Center, Dayton, OH

## ABSTRACT

The purpose of this study was to evaluate the effectiveness of a Functional Electrical Stimulation (FES) treatment program designed to prevent glenohumeral joint stretching and subsequent subluxation and shoulder pain in stroke patients. Twenty-two recent hemiplegic stroke patients with shoulder muscle flaccidity were randomly assigned to either a control group (n=11, 6 female, and 5 male) or experimental group (n=11, 6 female, and 5 male). Both groups received the conventional physical therapy. The experimental group received additional FES therapy where two flaccid/paralyzed shoulder muscles (supraspinatus, and posterior deltoid) were induced to contract repetitively up to 6 hour/day for 6 weeks. Duration of both the FES session and muscle contraction/relaxation ratio were progressively increased as performance improved. The results showed significant improvements in arm function, EMG activity of posterior deltoid, range of motion and reduction in subluxation (as indicated by x-ray) in the experimental vs control group. We concluded that the FES program was effective in reducing the severity of shoulder subluxation and pain, and possibly facilitating recovery of arm function.

## INTRODUCTION

Shoulder subluxation in hemiplegic stroke patients is a major problem in the rehabilitation of this population (1-4). In response to an upper motor neuron lesion, the normal neural control and voluntary function of the muscles are interrupted leaving the joint capsule and ligaments as the only protective mechanism against gravity. In the absence of muscle function, the capsule will frequently stretch, resulting in shoulder subluxation. The downward traction that the dependent arm imposes may cause damage to all supporting structures of the shoulder. This has been associated with increased pain, as well as an increased incidence of inappropriate autonomic responses (i.e., sympathetic dystrophy) in the upper extremity (5). The traditional method for addressing this problem is to employ some type of sling to achieve support (2,3). Placing the arm in a position of support helps to decrease pain for some patients. However, this position of the arm is not advantageous for functional activities. This is due to the fact that the arm is frequently held in a flexed and adducted position which may enhance the flexor synergy of the upper extremity.

Baker and Parker (6) used FES-induced contractions of the flaccid shoulder muscles for the purpose of reducing existing subluxation. The authors measured the shoulder subluxation by taking an anterior-posterior x-ray of both involved and uninvolved shoulders. Their results showed a significant decrease in the degree of shoulder subluxation. However, most patients who received this intervention were unable to attain full reduction of subluxation after six weeks, which may have been due to the high degree of subluxation present prior to the initiation of FES. It also should be noted that none the patients were treated prophylactically with FES during the acute phase of recovery. It has been suggested that if stretching of the joint capsule could be avoided during the acute and flaccid phase of neural recovery, many patients would develop sufficient muscular activity to maintain the glenohumeral joint in normal alignment after the recovery phase (1,2,5,8).

Therefore, the purpose of this study was to apply FES therapy during the acute phase (within 4 weeks) of stroke to determine if shoulder subluxation could be prevented, and recovery of arm function could be facilitated.

## METHODS

After the informed consent document was signed, 22 recent hemiplegic stroke patients with shoulder muscle flaccidity/paralysis were randomly assigned to either a control group (n=11, 6 female, and 5 male) or experimental group (n=11, 6 female, and 5 male). The mean ± SD height, weight, and age for the experimental group were 174±7 cm, 76±12 kg, 65±13 yr, and for the control group were 166±10 cm, 78±11 kg, and 69±12 yr, respectively. A preliminary medical evaluation was used to derive information regarding the cardiac and medical history for each individual participating in this study. For safety of the FES group, a baseline ECG, as well as detailed cardiac history review was completed. Individuals with cardiac pacemakers were excluded from this study. Patients with cardiac deficits, especially conduction problems, were monitored closely by ECG during the initial trials of the FES program.

All subjects were tested for arm muscle tone, surface EMG of the posterior deltoid muscle, various arm functions (modified Bobath technique; 7), sensory, upper arm girth, shoulder lateral range of motion for assessment of pain in the involved shoulder (10), and subluxation via x-rays of both shoulders. These evaluations were performed at three time periods: 1- at the start of the program (T1); 2- at the completion of the 6-week program (T2); and, 3- six weeks after completion of the program (T3). To verify reliability of the test data, all of measurements were also performed on the uninvolved shoulder.

### Radiological Technique

Anterior-posterior x-rays of both shoulders were taken of all patients at T1, T2, and T3. X-ray analysis was done by one designated investigator on a portable viewing box. No FES was performed for 24 hours before final x-rays were taken to eliminate short-term effects of facilitation that may occur. A modification of the distance measured from a single anterior-posterior radiograph described by Prevost and colleagues was used (9). For this, three initial reference points were determined: 1- central point of the glenoid fossa, 2- central point of the humeral head, and 3- most inferior and lateral point on the acromial surface of the acromioclavicular joint. The vertical component of the glenohumeral alignment

(V) was determined by measuring the vertical distance between the acromial point and the central point of the humeral head. The horizontal component (H) was measured as the horizontal distance between the central points of the humeral head and the center of glenoid fossa.

**Treatment**

Both groups received conventional physical therapy as part of their treatment program. The experimental group received additional FES therapy where two flaccid/paralyzed shoulder muscles (supraspinatus and posterior deltoid) were induced to contract repetitively up to 6 hour/day for 6 weeks. Duration of both the FES session (1.5 to 6 hours/day) and muscle contraction/relaxation ratio were progressively increased (10/12 sec to 30/2 sec on-off) as performance improved. A commercially available stimulator (Medtronic, Respond II) and two surface electrodes were used. This device has adjustments for the on-off stimulation cycle and the intensity of stimulation, as well as having a timer to start and stop the stimulation. The active electrode was placed over the posterior deltoid muscle and the passive electrode was placed over the supraspinatus muscle utilizing a configuration which minimizes activation of the upper trapezius muscle (which can cause shoulder shrugging). Stimulation frequency was set at 35 Hz to create a tetanized muscle contraction. FES intensity was set to obtain the desired motion of humeral elevation with some abduction and extension to pull the head of the humerus into the glenoid cavity. The subjects were asked to use their wheelchair arm support between and during the FES sessions.

**Statistical Analysis**

The statistical method used to determine significant differences between the experimental and control groups was analysis of variance with repeated measures. This model has two between subject factors (group: experimental vs control; shoulder: involved vs uninvolved) and one within subject factor (three time periods). For all statistical testing, the .05 level of confidence was used.

RESULTS

For the uninvolved arms of both groups, there were no changes in any of the variables during T1, T2, and T3 evaluation periods. For the involved arms of both groups, arm function, muscle tone, and EMG during T1, T2, and T3 are presented in Figures 1. respectively. These results show significant increases in the arm function and EMG for both groups; however, the increases are significantly higher for the FES group. The significant increases in muscle tone were the same for both groups. There were no changes in the arm sensation for both groups throughout the study.

The results of arm girth (G), shoulder lateral range of motion (R), vertical and horizontal distances in the x-ray (V, H) are presented in Table 1. The arm girths were the same for the involved side for both group at the start of the program. However, after six weeks, the girth was increased (1 cm) in the FES group, whereas it did not change in the control group. During the 6-week follow-up (T3), arm girth for the experimental group was maintained, whereas it decreased (2 cm) in the control group. The results of shoulder lateral range of motion (R) shows that at T2 it decreased (more pain) in the control group, whereas it did not change in the experimental group. This motion decreased in both groups in their follow-up evaluation (T3); however, it was higher for the experimental group.

X-ray evaluations showed that the H value decreased in the experimental group with no change in the control group at the 6-week evaluation (T2). The control group showed an increase in their H value, and the experimental group returned to their T1 H value at the 12-week evaluation (T3). The V values decreased significantly in the experimental group, and increased significantly in control group at the 6-week evaluation. No further changes in V were found at the 12-week evaluation.

**Figure 1.** Evaluations of the arm function, muscle tone, and EMG activity of posterior deltoid muscle, on the involved side during pre (T1), post (T2), and six week follow up (T3) of the FES treatment program.

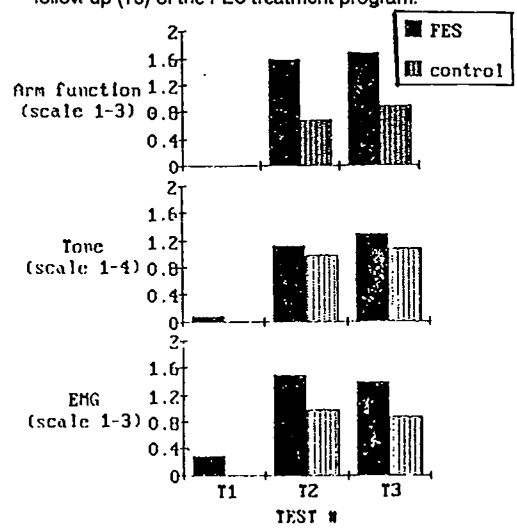


**Table 1.** The mean values ±SE of horizontal (H) and vertical (V) distance in mm, shoulder lateral range of motion (R), and girth (G) in cm of the involved (I) and uninvolved (U) sides of the experimental (E) and control (C) group at pre (T1), post (T2), and six week follow-up (T3) of the FES treatment program.

| | T1 | | T2 | | | T3 |
|---|---|---|---|---|---|---|
| | C | E | C | E | C | E |
| H(I) | 21±1 | 23±.8 | 21±1 | 22±.8 | 24±1 | 23±.8 |
| H(U) | 21±.6 | 23±.9 | 21±.6 | 23±.9 | 21±.6 | 23±.9 |
| V(I) | 39±.9 | 44±1 | 45+1 | 40±1 | 45±2 | 42±.9 |
| V(U) | 36±1 | 38±1 | 36±1 | 39±1 | 36±1 | 39±1 |
| R(I) | 55±8 | 60±6 | 37±7 | 58±7 | 30±5 | 49±8 |
| R(U) | 83±2 | 82±3 | 83±3 | 86±1 | 85±2 | 88±.9 |
| G(I) | 27±.6 | 30±1 | 27±.6 | 31±.6 | 25±1 | 30±.9 |
| G(U) | 27±.6 | 30±.9 | 28±.6 | 31±.9 | 28±.5 | 30±.9 |

## DISCUSSION

These results suggest that therapeutic FES intervention can be used to decrease shoulder subluxation and associated pain in hemiplegic stroke patients. The supraspinatus and posterior deltoid muscles are the most important muscles for maintaining the shoulder joint stability. The mechanism of action of the supraspinatus muscle is that it: 1- seats the head of the humerus into the glenoid fossa, 2- slightly abducts the humerus, and 3- externally rotates the arm. Both the capsule and supraspinatus muscle are horizontally aligned and prevent the head of the humerus from gliding down the glenoid fossa. Depression of the glenoid fossa, as a result of downward rotation of the scapula, causes adduction of the arm and, therefore, requires muscular effort to support the arm. This may well be a significant factor in the subluxation and painful dysfunction of the hemiplegic shoulder.

The basic action of deltoid contraction is elevation of the humerus along a line parallel to the humerus which tends to force the humeral head up against the coracoacromial ligament. When applying FES to these two muscles, the shoulder will be positioned in less adduction and internal rotation, thereby decreasing contractures. After 6 weeks of FES treatment in our experimental group, there was significant improvement in the arm function and EMG activity of posterior deltoid muscle. Indeed, this may be the result of faster recovery of these muscles. The increases in the girth measurements in this group may be the result of either faster arm function recovery or muscle strengthening due to FES-induced contractions. The lower H value in this group may be due to the activation of the supraspinatus muscle since one of the actions of this muscle is humeral abduction. On the other hand, the reduced V value in this group could be due to activation of the posterior deltiod and supraspinatus muscles which act to reduce the subluxation.

Although FES-induced contractions of shoulder muscles can pull the head of the humerus into the glenoid fossa to reduce subluxation, it is currently unclear as to the precise mechanism(s) for maintaining this effect when FES is removed. This was demonstrated during T2 x-ray evaluation when no FES was applied, and at the T3 x-ray evaluation when FES had not been applied for 6 weeks. We hypothesize that as a result of FES activation of supraspinatus and posterior deltoid muscles, there was less deterioration and faster recovery of muscle function. Thus, these muscles themselves appeared to maintain joint stability, alleviating the need for FES.

**Conclusion**: The results of our study agrees with previous suggestions (1,2,5,8) that if stretching of the joint capsule could be avoided during the acute/flaccid phase of neural recovery, many stroke patients would develop sufficient muscular activity to maintain the glenohumeral joint in normal alignment after the recovery phase. The avoidance of capsular stretching could reduce the incidence of chronic subluxation of stroke patients and potentially reduce the number of individuals experiencing pain or autonomic dysfunction in the hemiparetic upper extremity. Also, FES may result in faster recovery of arm function in these individuals. Further studies are necessary to investigate the use of longer periods of FES and the use of additional muscles for improving arm function and accelerating recovery.

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**Author Address:** Pouran D. Faghri, M.D., M.S.
Insitute for Rehabilitation Research and Medicine,
Wright State University,
3171 Research Blvd.
Dayton, Ohio 45420

P1.17

# FES-ASSISTED LEG-PROPELLED WHEELCHAIR

Roger M. Glaser, Bertram N. Ezenwa, Bill Mills, William P. Couch, Jose' W. Almeyda, & Doug Kremer

Institute for Rehabilitation Research and Medicine, Wright State University;
Veterans Affairs Medical Center; Rehabilitation Institute of Ohio, Miami Valley Hospital, Dayton, Ohio USA

## ABSTRACT

This paper describes a functional electrical stimulation (FES)-assisted leg-propelled wheelchair (FES-LPWC) for spinal cord injured (SCI) individuals. The system was designed to function as a conventional handrim-propelled wheelchair, and also to enable leg-propulsion via smooth transfer of motions generated by FES-induced contractions of paralyzed lower-limb muscles. During operation, the legs provide forward locomotion, whereas the arms are used for steering (as well as for forward or backward locomotion, if needed). Components include: a position feedback-controlled, multi-channel FES unit to induce bilateral synchronous or asynchronous contractions of the quadriceps and gluteal muscles for knee-extension, and the hamstring muscles for knee flexion; linear motion footplates with chain drives; independent left and right direct drive systems; and a common differential drive system to produce forward wheel rotation with knee extensions. Preliminary tests indicate that the design of this system offers improved locomotion and maneuverability over our previously described leg-propelled vehicle. This device can be further developed to offer an alternative means of locomotion for SCI individuals, and potentially contribute to better health, fitness and rehabilitation outcome.

## INTRODUCTION

Nine years ago, Glaser, *et al.* [1] tested the feasibility of using a leg-propelled vehicle to enable locomotion via functional electrical stimulation (FES)-induced contractions of the paralyzed quadriceps muscles of spinal cord injured (SCI) individuals. Locomotion with such a device may have advantages over conventional manual wheelchairs in that employment of the large leg musculature may result in improved locomotive capability, circulation in the lower-limbs, muscular and cardiopulmonary fitness, and self-image. In addition, secondary medical complications consequent to wheelchair confinement and sedentary lifestyle (e.g., deep venous thrombosis, decubitus ulcers, cardiopulmonary diseases) may be prevented.

Although the original leg-propelled vehicle demonstrated the concept of using paralyzed leg muscles for locomotion, it suffered from design deficiencies which made it impractical for everyday use in the field. For instance, it used only FES of the quadriceps muscles to produce knee-extension movements, and relied upon gravity to return the leg to the retracted position; the ratchet drive system provided limited maneuverability, and it was difficult to duplicate and adjust mechanically. Thus, it would be desirable to enhance the design of this device to make it more usable by SCI individuals in various environments, and to facilitate evaluation of its efficacy for improving locomotive capability.

Therefore, the purpose of this paper is to describe a newly designed FES-assisted leg-propelled wheelchair (FES-LPWC) which incorporates several advantageous design features. The design of this FES-LPWC enables more of the lower-limb musculature to be employed, provides improved maneuverability, permits easy alteration in the mechanical advantage of the drive system, and facilitates duplication for field studies.

## METHODS

The FES-LPWC was designed to possess all the features of a conventional handrim-propelled wheelchair. In addition, special subsystems were incorporated to enable propulsion by way of back and forth (push-pull) motions of the legs whose paralyzed muscles are FES activated. During operation, the legs provide forward locomotion, whereas the arms are used for steering (as well as for forward or backward locomotion, if needed). To achieve this goal, construction required special considerations that differ from conventional wheelchair design.

Figure 1 is a photograph that shows the side view of the FES-LPWC. The conventional handrim propulsion system, moveable footplates of the leg propulsion system, and the multi-channel FES system are seen. Figure 2 schematically illustrates a side view of the FES-LPWC. For the proper seating position, the back support is tilted to the rear $10^{o}$ from the vertical and the bench is inclined toward the front $5^{o}$ above the horizontal. This facilitates the push-pull motions of the moveable footplates (A) that couple to the drive system. The wheelchair seat frame was constructed to accommodate mounting of the various FES-LPWC subsystems that are schematically illustrated in Figure 3 and briefly described below.

Left and Right Moveable Footplates. Each moveable footplate (A), consists of an aluminum plate attached to two parallel, near frictionless linear motion guides (K) that are mounted at an upward angle of $10^{o}$.

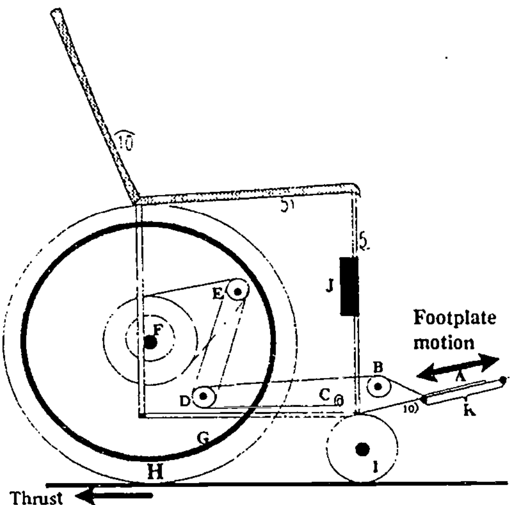

Figure 2. Side view of the FES-LPWC.

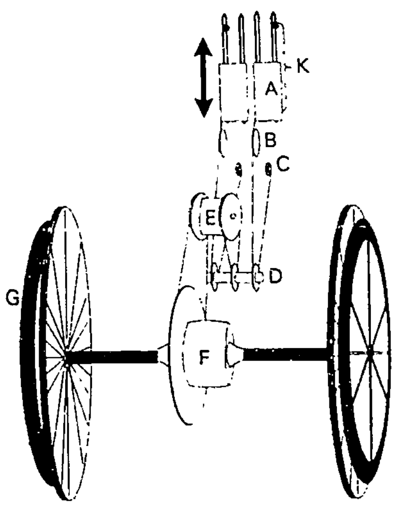
Figure 3. Top rear view of the FES-LPWC drive system.

This permits 23 cm of push-pull leg motion. Flexible plastic boots that are padded for foot and ankle safety are secured to the top of the footplates. When the foot is inserted into the boot, the leg is positioned at an angle of $5^{\circ}$ beyond the vertical. The heel end of each footplate is attached to a drive chain which is moved by that leg.

Direct-Drive System. Each drive chain couples a footplate by way of an idler (B) to a direct drive system using a sprocket with a ratchet mechanism. The chain terminates at a coil spring (C) which only has sufficient recoil to assist the retraction of the footplate and eliminate slack after a push stroke. The common shaft (D) of the left and right direct-drive systems is mounted by bearings, and it rotates only in the forward direction when either footplate is pushed forward due to the sprocket ratchet mechanisms.

Two-way Coaster Drive Mechanism. The common shaft of the direct-drive systems, in turn, is coupled via chain and sprocket to a two-way coaster drive mechanism (E). This provides immediate transfer of applied forward motion to forward rotation of the differential drive system (F) that turns the wheelchair wheels for forward propulsion. This design enables the wheelchair to coast forward at the end of each forward footplate thrust, and during retraction of the footplate. The two-way coaster drive mechanism also permits the wheelchair to coast in the reverse direction which provides total maneuverability during handrim propulsion or when pulled backwards by an attendant.

Differential Drive System. In order to propel the wheelchair by independent application of force to the left or right wheel (via arms or legs), a differential drive system (F) was incorporated as the drive shaft between the wheels. This differential drive system also enables steering of the FES-LPWC by creating bilateral differences in wheel velocities, or antagonistic forward and backward wheel rotations. Frictionless bearings were used to mount the axle to enhance efficient transfer of arm or leg propulsion thrust to the point of contact between each wheel and the ground.

Multi-Channel Functional Electrical Stimulation System. A battery-powered, six-channel FES system (J) is used to induce contractions in paralyzed lower-limb muscles to cause push-pull motions of the legs for wheelchair propulsion. Left and right leg muscles may be activated to contract in a synchronous or asynchronous pattern. For pushing action, both the quadriceps and gluteal muscles receive simultaneous FES. Footplate retraction is accomplished by gravity ($10^{\circ}$ upward tilt), the recoil spring (C), and FES activation of the hamstring muscles. The FES system also incorporates position feedback sensors (microswitches) on the linear guides (K) to automatically control activation of the muscles (i.e., FES timing and duration) at appropriate positions of the moveable footplates. This feedback circuitry also enhances safety of the FES-LPWC since it prevents rapid impact upon the legs which would occur if the footplates were permitted to abruptly reach the end of their motion range.

## EVALUATION AND RESULTS

To operate the FES-LPWC, FES surface electrodes are placed over motor points of the paralyzed quadriceps, gluteal and hamstring muscles of an SCI individual. After securing the left and right feet in their respective boots, the multi-channel FES system is switched on and contraction thresholds are set. Either a synchronous (both legs move simultaneously) or an asynchronous (legs move reciprocally) contraction pattern is selected, and manual or automatic operation is selected. With manual operation, the contraction sequence is initiated each time a switch is pushed. With automatic operation, contraction sequences occur at an adjustable, repetitive rate. The feedback position sensors (K) control the FES duration for each stroke, and provide the signal to switch from the quadriceps/gluteal pushing stroke to the hamstring pulling stroke. Thus, hamstring muscle FES only occurs at an extended leg position. If the legs muscles fatigue during locomotion, FES is discontinued, and the FES-LPWC can be propelled as a conventional wheelchair via the handrims.

The newly designed FES-LPWC has undergone preliminary testing with several SCI subjects. For this, a relatively straight and level 20 m indoor course with a smooth cement floor surface was used. Subjects were able to propel this device via FES-induced contractions at approximate velocities of 0.2-0.3 m/sec. Locomotion was initiated by using manually-controlled, synchronous leg movements, and then switching to automatically-controlled asynchronous leg movements for smoother, more continuous motion. The entire 20 m course was easily traversed by subjects who were well-trained in FES-induced knee-extension exercise. Operating the FES-LPWC with the upper-body via the handrims was found to be similar to conventional manual wheelchairs with respect to propulsion and maneuverability.

## DISCUSSION

Although conventional handrim propelled wheelchairs are important for the mobility of SCI individuals, there are inherent problems associated with these devices that can hinder the rehabilitation process and lead to serious secondary disabilities [2-5]. These problems relate to: the use of the relatively small upper-body muscle mass which is highly fatigable; inactivity of lower-body muscles which leads to atrophy, osteoporosis, decubitus ulcers, blood pooling in the legs and greater risk for deep venous thrombosis formation; and, marked loss of cardiopulmonary (aerobic) fitness.

Therapeutic FES-induced exercise of the lower-limbs of SCI individuals (e.g., knee-extension, leg cycling) has been shown to enhance the strength and endurance of the activated muscles, peripheral and central circulation of blood, and cardiopulmonary function [6-8]. Thus, FES can potentially prevent/alleviate secondary disabilities and permit a more active lifestyle. The concept of using FES-induced contractions of paralyzed lower-limb muscles of SCI individuals for propulsion of a vehicle appears to have far reaching merit. Use of the larger lower-body muscle mass, and the repetitive contractions involved, may provide superior exercise characteristics and contribute to improved health and fitness, as well as improved locomotive capability.

The FES-LPWC incorporates design improvements over the previously described leg propelled vehicle [1]. Utilization of the direct drive system, two-way coaster drive mechanism, and differential drive system provides greater mobility and maneuverability than the previously used ratchet drive system. In addition, the multi-channel FES system enables use of more muscle groups to enhance locomotive performance and provide greater exercise benefits. It is also possible to operate the FES-LPWC with both the arms and legs simultaneously to incorporate even more muscle mass, and possibly derive greater locomotive and exercise benefits. Laboratory testing is needed to determine metabolic (energy cost) and cardiopulmonary responses for this mode of locomotion, and to provide insight into design modifications which will increase mechanical efficiency and other operating characteristics. It appears that devices such as the FES-LPWC can offer an alternative means of locomotion for SCI individuals, and potentially contribute to higher levels of health, fitness and rehabilitation outcome.

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Roger M. Glaser, Ph.D., Director
Institute for Rehabilitation Research and Medicine
Wright State University Research Center
3171 Research Boulevard
Kettering, OH 45420

# COMPUTER-CONTROLLED HYBRID EXERCISE SYSTEM FOR SCI INDIVIDUALS

Bertram N. Ezenwa, Stephen F. Figoni, Roger M. Glaser, Bill Mills, William Couch, Jose' Almeyda, Clarence Wu.
Institute for Rehabilitation Research and Medicine, Wright State University School of Medicine, V.A. Medical Center, and Miami Valley Hospital, Dayton, OH.

## ABSTRACT

This paper describes a linked arm crank and leg cycle ergometer for combined computer controlled functional electrical stimulation (FES)-assisted leg cycle and voluntary arm crank (hybrid) exercise for spinal cord injured (SCI) individuals. Components were implemented to enable the use of this hybrid exercise system in an upright and a range of recumbent postures. Its seat is fully adjustable to accommodate individuals of various heights and limb lengths. To measure the force contributions of the arms and legs independently during hybrid exercise, specially designed strain-gauge systems were built into the arm crank and leg pedals. Preliminary tests indicate that computer-controlled FES can be delivered to the desired muscles at the appropriate crank angles, and that this hybrid exercise system can be used for muscular and cardiopulmonary fitness training of SCI individuals.

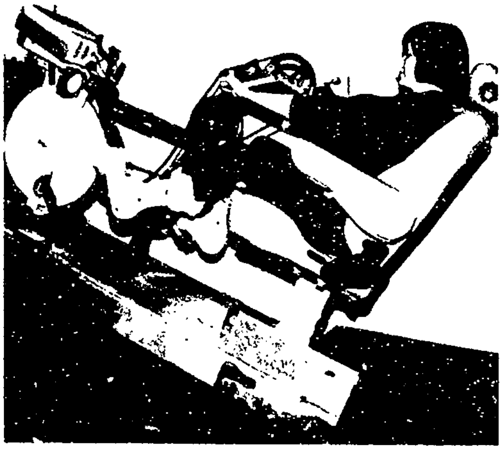
## BACKGROUND

Previous studies have shown that exercise is an extremely important treatment modality to develop physical fitness and functional independence for quadriplegic and paraplegic individuals [1]. It may also play a preventative role during and following the rehabilitation process by maintaining fitness since cardiovascular and respiratory disorders are prevalent causes of morbidity and mortality in the SCI population [2]. During the acute phase of rehabilitation, circulatory adjustments to changes from supine to upright postures are frequently impaired [3,4]. This is because the hydrostatic load due to gravity opposes the return of venous blood from the lower body to the heart. This condition can result in orthostatic hypotension which can reduce arterial blood flow to the brain, and lead to a loss of conciousness. Figoni, *et al.* [5] studied quadriplegic individuals performing arm cranking exercise in the sitting and supine postures. They found that maximal power output, peak oxygen uptake, ventricular stroke volume and cardiac output were significantly higher in the supine position. This appears to be due to the facilitated venous return of the blood to the heart which in-turn enabled the delivery of more blood to the exercising arm muscles. Four studies completed in our laboratory have shown that in SCI subjects performing arm-cranking exercise in the sitting position, the addition of either knee extension exercise or leg cycling exercise via functional electrical stimulation (FES)-induced contractions of paralyzed muscles can increase peak oxygen uptake above levels achieved by the arms alone [5-8]. This is most likely due to the additional muscle mass utilized with *hybrid* exercise. Furthermore, the induced lower-limb contractions may activate the venous muscle pump and enhance peripheral and central circulation. It appears feasible that this additive metabolic and cardiopulmonary effect may be more pronounced if the exercise is conducted in a recumbent position where the reduction in hydrostatic pressure may further promote venous return of blood to the heart. Although there appears to be advantages in combining the various exercise techniques to optimize training capabilities of SCI individuals, no composite system was available for evaluation. Therefore, the purpose of this project was to design and construct a hybrid exercise system to enable simultaneous voluntary arm cranking and FES-induced leg cycling in the sitting and recumbent postures.

## METHODS

The hybrid exercise system was designed to incorporate combined computer controlled FES leg cycling and voluntary arm cranking exercise by way of a linked ergormeter configuration. It possess the versatility to be operated in different postures and to accommodate individuals of various heights and limb lengths. The contributions of the arms and legs to the total power output can be continuously monitored independently by force sensors in the arm crank and leg pedals. Figure 1 is a photograph of the hybrid exercise system being operated in a semi-recumbent posture. Figure 2 is a diagrammatic illustration of the side view of the device in the lowered position (for upright exercise) showing details of the various linkages and subsystems. Figure 3 diagrammatically illustrates the device in a raised position position for semi-recumbent exercise. The following are the details of the subsystems.

*Computer Control of FES.* An IBM microcomputer (Figure 2 H) was used to implement computer control of FES. The program for this was written in Forth and run under "ASYST" software package by Keithley Co. During operation, real-time data are obtained regarding pedal position within a crank cycle by masking digital pulses from sprocket teeth (via infrared sensors) between $0^{o}$ and $360^{o}$ crank angle. These data are used to control the phase (on-off time) of FES current application to the selected muscle groups. The computer program is used to set the FES intensity level for each muscle group prior to initiating an exercise. It is also used to acquire and store the force values applied by the arms and legs, independently.



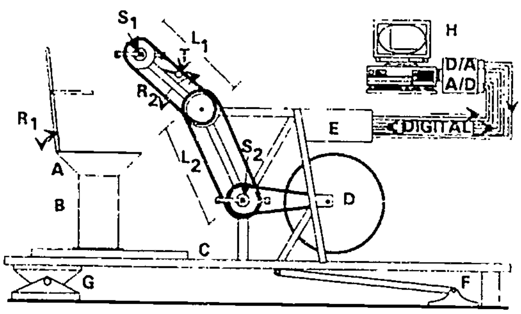



Figure 2. Side view of the computer-controlled hybrid exercise system for use with a subject in the upright posture.


Figure 3. Illustration of optional use of the hybrid exercise system in the recumbent posture.

***The Seat: Vertical and Horizontal Adjustments.*** The seat, and its vertical and horizontal position adjustments are illustrated in Figure 2 A, B and C, respec 'ively. The back support of the seat is adjustable from the vertical to the horizontal position. It also has side supports to keep the body and legs centered and stable. The vertical adjustment (B) is a two-stage telescoping motor-driven pillar (Magnetic Corporation) which has a 0.6 meter differential height adjustment. It is capable of withstanding a 2,000 N load, 1 meter off the center. The horizontal adjustment of seat position is implemented with ball-screw motor-driven linear motion guide system (C) which is capable of withstanding 4,000 N load. The ranges of vertical and horizontal travels were chosen so that SCI individuals could sit and reach the arm crank and leg pedals comfortably.

***The Coupled Arm-Crank and Leg-Cycle Ergometer.*** The arm-crank and leg-pedals are coupled so that they drive a common flywheel (D). This is achieved by 1) linking the leg pedals to the flywheel through a chain and sprocket arrangement, and 2) linking the arm crank to the leg pedals by a two-stage chain and sprocket arrangements ($L_1$ and $L_2$). While $L_2$ has a double-sprocket, double-chain configuration to facilitate linkage with $L_1$ and the flywheel, respectively, $L_1$ has a single-sprocket configuration. There are provisions also in $L_1$ to facilitate angular adjustment ($R_2$) in a vertical plane to set the distance between the arm crank and leg pedal for each individual. The idler/tensioner (T) is used to prevent slack in the drive chain as a result of $L_1$ angular adjustment.

***System Base Angular Adjustment:*** The hybrid ergometer is mounted upon a high-tensile, light-weight aluminium base plate. The base is designed to pivot about the seat end (Figure 3 G) utilizing a shaft and bearings. Elevation of the front end of the base plate is accomplished by a motor-driven two-stage pillar (Figure 3 F). The maximum angular displacement is $30^{o}$ from the horizontal. To provide a counter balance during upward tilt of the ergometer, the pivot (G) and the drive (F) are secured on a heavy steel slab which has two sections which disassemble for ease of transportation.

***Electrical/Electronics Subsystem.*** This subsystem, which is illustrated as E in Figures 2 and 3, is composed of two parts. The first is an eight-channel FES system whose crank angle-dependent on-off timing for each muscle is controlled by a microcomputer via digital masks (as indicated above). FES intensity levels are also set via D/A signals from the microcomputer. The second part is a real-time data conditioning and display system for cadence (RPM), current intensity levels, and forces of arm cranking and leg cycling. These data are also stored simultaneously in the microcomputer.

***Arm Cranking and Leg Cycling Force Measurement.*** In order to measure the force generated during arm cranking and leg cycling independently, special force sensors that are integral components of the arm crank and leg pedal shafts ($S_1$ and $S_2$ in Figures 2 and 3) were constructed. Figure 4 A illustrates the detail of these sensors, showing that they are designed to provide a force output signal only when a tangential force is applied to them. The male section (B) consists of four fingers which matches the female section (C). Each finger has a narrow section cut-out to assure that bending tendencies are referred to them, and strain-gauges are mounted symmetrically on both sides of each cut-out. Electronic data conditioning provides all positive output signals from the strain-gauges.

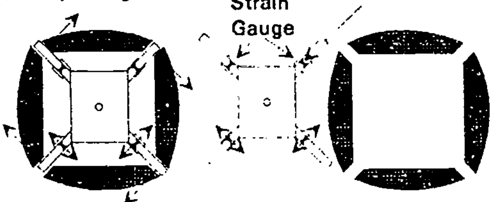



Figure 4. (A) Schematic representation of the cross section of a system to measure the force of arm-cranking and leg-pedalling independently. (B) and (C) illustrate the male and female sections respectively.

## SYSTEM EVALUATION AND CONCLUSION

Preliminary evaluation of the hybrid exercise system was conducted to determine hardware and software performance and limitations. Subjects with various physical dimensions were used to test the adjustability of the seat and ergometer arm crank/leg pedal reach. It was found to accommodate all the size variations anticipated for the targeted subject population. Individuals reported that the seating arrangement was stable and conducive to exercise. When tilting the ergometer upwards from the upright to semi-recumbent postures, the body geometry remained constant so that studies can be performed on different gravitational loads without changing exercise configuration. Computer control of FES application to the muscles was found to be accurate up to 40 RPM cadence. Beyond 40 RPM, FES control lagged behind cadence. This resulted from the multi-channel, multi-tasking limitation overhead of the host computer package ("ASYST"). Although we can utilize 40 RPM cadence for most quadriplegic subjects, it will be desirable to operate at 50 RPM cadence for paraplegics. The system can be developed further utilizing programming microprocessors for FES control instead of using the ASYST software package with the microcomputer. This will also facilitate the use of the ergometer outside of the laboratory environment. This hybrid exercise system can potentially enable SCI individuals to achieve higher levels of muscular and pulmonary fitness than with either the arm or leg exercise mode alone. Research is currently underway to evaluate the efficacy of this multi-mode exercise system.

## ACKNOWLEDGEMENT

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Author Address: Bertram N. Ezenwa, Ph.D.
Institute for Rehabilitation Research & Med
Wright State University School of Medicine
3171 Research Blvd
Kettering OH 45420

P2.1

# Competency Based Staff Training for Physical and Nutritional Management Programs

Rita K. Handley, MOT, OTR & Karen Hardwick, MEd, OTR
Texas Department of Mental Health and Mental Retardation
Austin, TX

## Abstract

This presentation describes a competency based training program designed for staff who care for individuals with severe physical and neurological dysfunction. The program includes instructional videos and written materials which address handling, transferring, specialized seating and positioning, feeding techniques and equipment, prevention of choking, and other care issues for individuals with developmental disabilities.

## Background

Direct contact staff who care for individuals with severe physical and neurological dysfunction often have little education and experience in that area. This program was developed to prepare staff for their roles in implementation of integrated physical management programs which are an essential part of the treatment for developmentally disabled individuals. Such programs may require staff to use specialized seating and positioning to normalize muscle tone and enhance function; carry out feeding programs to improve health and nutritional status; and perform individualized handling and transfer techniques. This program was designed to help nonprofessional staff develop a working understanding of the rationale underlying the various aspects of care involved in physical management programming as well as the specific techniques required to implement individual plans of care.

## Objective

This program was formulated to insure a consistent method of providing the necessary knowledge and skills for staff to carry out comprehensive physical management activities. Because of the complex nature of some programs and the potential negative impact on the individual from lack of consistent implementation, a standardized method of insuring staff competency was essential.

## Description

The training modules contain both didactic and practicum components. The didactic part of the training program is designed to provide basic information about developmental disabilities, therapeutic techniques, and specialized equipment which is used to enhance function in this population. The practicum component includes sensitivity exercises as well as teaching specific physical management skills. Each unit contains specific learning objectives, vocabulary, instructional video tapes, and evaluation instruments.

The complete training program is comprised of six competency based modules and addresses the following subjects: Normal and Abnormal Development; Developmental Disabilities; Body Mechanics; Therapeutic Handling and Positioning; Oral Structures; and Promotion of Optimal Eating Skills. The fifteen to twenty minute instructional video tapes which accompany each module were designed to provide information in a concise and easily understood format. The evaluation instruments are clinically based case studies designed to assist the student in practical application of the information presented in the video tapes. In addition to the materials used in the classroom situation each participant receives a manual containing the learning objectives, vocabulary used in the module, a description of practicum exercises, pictorial training aids, and copies of the skill mastery checklists used to document competency in the various areas.

## Method

The purpose of the seminar is to provide information about a structured, competency based training model for staff working with severely handicapped individuals. The modules were designed to address developmental problems that interfere with functioning and cause secondary disabilities.

The presentation includes lecture and visual aids. The lecture describes the instructional design and content. Visual aids show examples of program components. Instructor's and participant's manuals and testing materials will be available for review.

At the end of this presentation the participants should be able to identify the activities included in a comprehensive physical management program and describe appropriate training methods and materials for staff working with severely disabled individuals.

## Discussion

Unlike most training programs which are available, the focus of this series is on skills and techniques appropriate for use with adults who exhibit physical and developmental disabilities. The skills which are demonstrated are appropriate for use both in residential facilities as well as small community homes. The presentation is geared largely toward nonprofessional staff who are responsible staff who are responsible for most activities of daily care.

These training modules were designed to be used in a variety of instructional settings. If necessary, the didactic and practicum components may be taught by qualified, non-professional staff. Because of the content and scope of the instructors manual, specially trained instructors should be able to answer questions about the material and discuss basic concepts. There are, however, certain parts of training which are better served through involvement of rehabilitation professionals. Initial on the job training and determination of skill/ competency should ideally be performed by professional staff. Individual modules are self-contained and can readily be used for refresher training, individual self-paced study, or inservice education.

Rita K. Handley, MOT, OTR
Assistant Deputy Commissioner for Physical Health and Nutritional Management
Texas Department of Mental Health and Mental Retardation (TXMHMR)
P.O. Box 12668
Austin, Texas 78711-2668

Karen Hardwick, MEd, OTR
Director of Habilitation Therapies
TXMHMR - Austin State School
P.O. Box 1269, 2203 West 35th
Austin, Texas 78767

P2.2

# Rehabilitation Engineering Opportunities Under The Americans With Disabilities Act

William A. Hyman
Bioengineering Program
Texas A&M University
College Station, Texas

Abstract

The Americans with Disabilities Act (ADA), signed into law on July 26, 1990, mandates certain actions in both the public and private sectors to eliminate discrimination against individuals with handicaps in the areas of employment, transportation, public services, public accommodations and telecommunications. The act also provides legal remedies for individuals who are discriminated against. The legislative history, as well as the act, calls for the use of technology as part of the requirements of accommodation. These requirements present a number of new opportunities for the application of rehabilitation engineering services.

## Introduction

The ADA has been called the Emancipation Proclamation for those with disabilities. Consisting of five major sections, the ADA will bar discrimination by both private business and governments in public accommodations and services, telecommunications, and employment. While access to buildings and transportation is reasonably well understood, the employment provisions of the ADA are unique in the requirements for providing, on an individual basis, "reasonable accommodation". (Postol and Kadue, 1991). These provisions take effect in July, 1992 for employers with 25 or greater employees, and in July, 1994 for employers with 15 or greater employees. Reasonable accommodation can include facility access, reassignment, modified schedules, job restructuring, acquisition or modification of equipment, and similar measures. Technological approaches to such accommodation, including specific examples, was anticipated in the legislative history of the ADA (House and Senate Reports). Such accommodations must be made unless they present "undue hardship" to the employer, i.e. an action requiring significant difficulty or expense. Factors to be considered in the evaluation of undue hardship include the nature and cost of the accommodation, the financial resources of the employer, the number of persons employed, the effect of the accommodation on other operations, and related matters. Technological input will be required in three areas; evaluation of requirements for feasibility and cost, the implementation of selected aids, and the resolution of disputes relating to whether accommodation should have been made.

## Evaluation

When the issue of accommodation first arises it will be necessary in many cases for the employer to obtain an initial study of what accommodations are appropriate for an individual candidate, and whether these accommodations can be provided without undue hardship. Addressing this question includes traditional employment counselor and rehabilitation engineering and technology activities. This might be done by in house, by a state or other vocational counselor, or by outside consultants. The objective would be to identify what would have be de done, what it would cost, and other implications of implementation. These factors would enter the employers decision as to whether or not the accommodation was reasonable.

## Implementation

Following a favorable evaluation and decision by the employer, the technical aspects of the accommodation must be implemented. Depending on the scope and complexity of what is needed, the accommodation may involve a range of devices from off-the-shelf equipment to custom design. The equipment must also be setup at the workplace along with any other physical modifications. As with many rehabilitation applications, this may involve vendors, technologists, engineers and other providers. Cost sharing between provider and employer may also have to be resolved if the burden would be unreasonable on the employer alone. It will also be appropriate in most cases to provide follow-up evaluation to make sure that the accommodation is successful from the point of view of both the employee and the employer. More long term follow-up may also be necessary as the requirements change or the employee is considered for other work. The latter is an important consideration in that, having overcome any initial barriers to employment, the worker should not be discriminated against with respect to opportunities for advancement.

## Dispute Resolution

It has been predicted that among other effects, the ADA will generate a significant number of allegations of discrimination with the need to resolve these either administratively or by litigation. The administrative procedure involves filing a charge with the Equal Employment Opportunity Commission (EEOC). If the EEOC does not initiate proceedings against the employer it must issue a right-to-sue letter to the complainant who may then initiate civil litigation. It can be anticipated that the nature and reasonableness of accommodation will play a significant role in such disputes. An initial evaluation would be significant with respect to conclusions that accommodation was not feasible or that it would it be too costly. In the absence of an initial evaluation one would probably have to be done in defense to prove that the employer had acted properly in not accommodating the worker. Similarly, the plaintiff worker would want to have their own evaluation in order to establish, if possible, that accommodation should have been made. Since the plaintiff evaluation can be expected to result in a proposed solution to the accommodation problem, the defense side will be further required to explain why the plaintiff's plan was not suitable. Thus, as in many litigation areas, the "experts" on each side will play an important role in providing evidence on whether or not accommodations should have been provided.

## Conclusion

The ADA will require a new level of effort to provide technical accommodations to workers or applicants with disabilities. While such activities have been ongoing, federal requirements will no doubt increase the demand for rehabilitation engineering and technology services. These services will be necessary in order to provide evaluations of what adaptations would be required, and what they would cost, in order to accommodate particular workers to particular jobs. They will also be necessary when feasible accommodations are identified and chosen for implementation. Finally, rehabilitation engineering studies will also be required in the dispute resolution phase of the ADA when a claim of denied accommodation must be analyzed.

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William A. Hyman
Bioengineering Program
Texas A&M University
College Station, Texas 77843

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# ASSISTIVE TECHNOLOGY CLINICS: AN INTERDISCIPLINARY, COMPREHENSIVE PEDIATRIC EVALUATION


Michelle L. Lange & Cheryl S. McDonald
AccessAbility Resource Center
The Children's Hospital of Denver
Denver, Colorado



## ABSTRACT

The Assistive Technology Clinics at The Children's Hospital in Denver strives to provide an interdisciplinary, comprehensive evaluation for children who may benefit from assistive technology. Clinics include Positioning and Mobility, AccessAbility, Augmentative Communication, Learning Enhancement, and Environmental Controls. Team members include an occupational therapist, physical therapist, rehabilitation engineer, physician, speech language pathologist, and learning specialist. The evaluation process begins with enhancing community awareness in order to reach those in need of technology. The assessment is family-centered and designed to promote choice. The process concludes with follow through of recommendations; including funding, resources, and training.


## BACKGROUND

As the physically challenged population continues to grow in number, the variety of technology available to meet their special needs expands internationally. However, when faced with such a vast array of technology, the need for evaluation becomes even more apparent. The technology user, family, and those working with the user need to be informed as to what assistive technology is available, and assisted in identifying which equipment will best meet their needs and/or goals.

Technology evaluations have often been fragmented, with many professional disciplines unrepresented, and/or not working together as a team. Families are often uninformed and, as a result, professionals often make recommendations without including the family in the decision. Clearly, there is need for a comprehensive, interdisciplinary approach. In conjunction with this need for appropriate evaluation, is the need for corresponding follow through, including the areas of funding, training, and on-going evaluation as the user's needs change. An ideal evaluation would prevent acquisition of inappropriate equipment which too often ends up on closet shelves, but would increase independence and quality of life through assistive technology.

## OBJECTIVE

The purpose of the Assistive Technology Clinics is twofold: 1) to provide an interdisciplinary, comprehensive evaluation of the child to determine which technology can best meet the user's needs and goals, and 2) to include the user/family as a part of the team and give them the information they need to make a decision.

## METHOD/APPROACH

### Referrals

The Assistive Technology Clinics have served users from all over the United States. Referral sources include physicians, therapists, educators, parents, and users themselves. Both inpatient and outpatient populations are represented. The program also attempts to increase community awareness, and thus, help find those in need of technology who are not receiving services.

Once a referral is received, all pertinent information is gathered prior to scheduling the evaluation. Gathering of information includes a pre-evaluation questionnaire completed by the family, medical records, therapy reports, and school reports.

### Clinic Process

The Assistive Technology Clinic's staff consists of an Occupational Therapist, Physical Therapist, Rehabilitation Engineer, Rehabilitation Physician, Speech Language Pathologist, and Learning Specialist. Other disciplines who can be included as needed are a Lekotek leader (adaptive toys and play), parent advocate, social worker, and recreational therapist. The Assistive Technology Clinics consist of Positioning and Mobility, AccessAbility, Augmentative Communication, Learning Enhancement, and Environmental Controls.

The evaluation process begins with a parent conference, attended by all team members. The family is a vital part of the team. Friends, family members, or other professionals working with the user are welcome, at the user's invitation. At this conference, the user and family are encouraged to express their goals for the evaluation. The staff reviews information previously gathered with the team.

Positioning and Mobility Clinic. The Positioning and Mobility Clinic begins with examination by the physician and the physical therapist. Orthopedic concerns, as well as influence of joint range of motion, muscle tone, and primitive reflexes as relevant to seating, are identified at this time. Now the child is positioned. Frequently a modular Seating Frame is utilized, which is a component system that allows simulation of a custom linear seat. This system can include an anti-thrust seat, which has been found extremely beneficial for children with extensor posturing. The seating frame is mounted on an Invacare Arrow power base which can be adapted to multiple access methods. Once a child is positioned optimally, an access method is determined for mobility. This may include joystick, multiple switch array, single switch scanning, sip and puff, RIM control, etc. Mobility skills are then explored in conjunction with access assessment. Skills explored may include cause and effect, stop and go, turning, steering, negotiating obstacle courses, ramps, doors, etc.
The Positioning and Mobility Clinic concludes with a Summary Conference at which time a mutually recommended seating system and/or mobility devices may be ordered.

AccessAbility Clinic. Access to technology is assessed during the entire evaluation process. Access is considered in terms of how the user interacts (or needs or would like to interact) with every aspect of his or her environment. Access also impacts how devices may interface with one another.

Augmentative Communication Clinic. Clinic resumes the next day with another parent conference at which time specific augmentative and learning issues/goals are identified. The Augmentative Communication Clinic is staffed by a speech language pathologist and an occupational therapist, if access is an issue. In this clinic, team members evaluate a child's potential for communication and match needs with features of particular communication devices. Light tech as well as high tech systems are explored.

Learning Enhancement Clinic. The Learning Enhancement clinic is staffed by a speech language pathologist with special training in special education and an occupational therapist, if access is an issue. Through use of computer technology, team members evaluate a child's potential to use appropriate educational programs as a means to facilitate learning and language growth whenever use of conventional education methods are difficult for the child.

Environmental Controls Clinic. Finally, environmental controls are examined by the occupational therapist. A wide variety of systems are considered and matched to the user's access capabilities, control needs, and general cognitive skills.

At the conclusion of these clinics, the Assistive Technology Clinic staff meet again for a staffing to review the evaluation and recommendations. During this time, the user and attendees have a recess with time to reflect on the evaluation, discuss issues and formulate questions. Finally, a Summary Conference is held, with all team members present, during which the entire evaluation is reviewed. Recommendations and further information are presented to the user to better enable them to make an informed choice as a team member. Questions are addressed and follow-up is discussed and begins.

Follow-up

During the Summary Conference, the user/family is given a Question and Answer form as well as a Summary form which lists goals, recommendations and resources for the family. The family receives formal reports and a post-evaluation questionnaire by mail. Follow-up calls are made at 1, 3, 6, and 12 month intervals, at which time status of the recommendations is checked. This includes equipment funding, order, delivery, and check-out. The physician writes a Letter of Medical Necessity and fills out any necessary forms which are sent to the equipment vendor to facilitate funding approval. If further documentation or justification is needed, the appropriate team member can provide this, as well. Following funding approval, the Assistive Technology Clinic verifies that an order has been placed and receives an estimated delivery date. Upon delivery, a team member checks out the equipment to verify that the equipment is correct and to begin any needed training.

Training is provided, as needed, either as a tool to further determine recommendations or to instruct the user, family or others in the use of obtained equipment. If the family lives out of the area, intensive training sessions are scheduled when the family can return or detailed training recommendations are made which are carried out in the home area. A user might be referred for re-evaluation at a later date, after achieving specified goals (ie. demonstrates stop and go concepts for mobility), or as needs change.

## RESULTS

Overall, the surrounding community has demonstrated increased awareness of technology resulting in more referrals for those in need of technology. Those professionals who are working with evaluees have been generally pleased with the evaluation, recommendations, and follow through. The most favorable results have been from the users themselves. Many who are physically challenged have achieved some independence in their lives for the first time during the Assistive Technology Clinics. Perhaps this was the first time they could move themselves through their environment independently, speak what was on their mind, or create and print a card to their mother on the computer. Satisfaction with availability of funding sources and quality of service from equipment vendors is an ongoing issue, one which the Assistive Technology Clinic team is striving to impact.
The Assistive Technology Clinic staff have found the team approach less frustrating and have been pleased with resulting recommendations, which are more coordinated. There has been a "streamlining" of equipment ordered. For example, if joystick access to a power wheelchair has been recommended, this access method may also be recommended for an augmentative communication system, and the two devices interfaced.

## DISCUSSION

Four major philosophies form the foundation of the Assistive Technology Clinic process. First, is a Team approach which is truly interdisciplinary and comprehensive. Second, is a Family Centered approach. The family is truly a member of the Assistive Technology Clinic team and their input, goals, and needs are stressed from referral through follow-up. Third is Promoting Choice. The user and family are provided with information in as clear and as organized a manner as possible to assist them in making an informed decision as a member of the team. Any time a decision is made throughout the process, the family makes the ultimate choice with input from the other team members. Finally, the Assistive Technology Clinic process is a Total approach. The staff do not just perform evaluations. The clinics identify needs, perform the evaluations, and follow through with all recommendations made and with training and re-evaluation needs. These philosophies help to ensure that the Assistive Technology Clinics do not merely provide recommendations, but result in effective technology which is used to promote increased independence and quality of life for those who are physically challenged.

## ACKNOWLEDGEMENTS

The Assistive Technology Clinics are a part of the Children's Hospital of Denver.

Michelle L. Lange, OTR
AccessAbility Resource Center
The Children's Hospital
1056 E. 19th Avenue
Denver, Colorado 80218

# DISABILITY MANAGEMENT WITHIN THE DEPARTMENT OF DEFENSE

Dinah F.B. Cohen, Program Director
Computer/Electronic Accommodations Program
Defense Medical Systems Support Center
Falls Church, VA USA

## Introduction

The Department of Defense (DoD) has taken a proactive approach towards disability management. Secretary of Defense Cheney has set department goals to increase representation of employees with disabilities from 1.2% to 2% by the end of fiscal year 1992. DoD is aggressively recruiting individuals with disabilities and, to support this goal, the Computer/Electronic Accommodations Program (CAP) was established in 1990.

CAP assists DoD agencies by providing adaptive devices for DoD employees with disabilities. The program is intended to eliminate a wide variety of barriers for people with disabilities who use DoD facilities and participate in DoD programs and activities. DoD has programmed $10.7 million through 1994, making CAP the largest and most innovative initiative in the Federal government to accommodate individuals with disabilities.

The CAP is a joint effort between the Assistant Secretary of Defense (Force, Management and Personnel) (ASD(FM&P)) and the Assistant Secretary of Defense (Health Affairs) (ASD(HA)). The Defense Medical Support Activity (DMSA), a field activity under ASD(HA), and one of its subordinate program offices, specifically the Defense Medical Systems Support Center (DMSSC), has been named the executive agent.

## Methods

To achieve DoD goals to support the recruiting, hiring and advancement of persons with disabilities, the CAP office identified two primary areas for program development. The first was to establish a mechanism for disseminating information and educating DoD organizations regarding disability management. The second was to develop an accommodation request process to ensure that appropriate adaptive devices are provided in a timely manner. These two initiatives are further discussed below.

In order for DoD goals to be met it is imperative that DoD managers, supervisors, Personnel/EEO officers, and DoD employees be aware of the issues of disability management, the ease with which they can be addressed, and the assistance available through the CAP office. The CAP office has instituted an information dissemination program to educate the DoD communicate. Our strategy includes conducting presentations, participating in conferences and exhibits, and completing site visits to build an infrastructure for information dissemination. To support these activities, the CAP office developed a variety of materials including display materials, a video, a folder and fact sheets, a brochure and letterhead.

Concurrent with the execution of the information dissemination program, the CAP office established the process for filling accommodation requests. This incorporates the completion of a needs assessment, identifying alternative solutions, coordinating with the employee with a disability to select the best alternative, procuring the accommodation and ensuring delivery, installation and training. The CAP office coordinates all accommodation requests with the requesting individual and assigned point of contact to ensure customer satisfaction. In addition to providing adaptive devices to improve accessibility to computer applications and capabilities, the CAP office supports long term (over five days) training with sign language interpreters.

Results

In fiscal year 1991, the CAP office participated in 47 events (such as conferences, presentations and exhibits) reaching over 7,000 individuals who are directly impacted by DoD disability management issues. This program has been extremely successful in getting the word out about CAP. As a result, CAP has provided nearly 1400 TDDs to offices and individuals requiring increased communication capability, and 932 accommodations for persons with hearing, vision and mobility impairments throughout the DoD community.

Discussion

Efforts continue to increase awareness of the CAP and the number of accommodations provided. Future program goals include:

- Continue to provide adaptive equipment to DoD employees with disabilities.
  - -- The FY 92 goal is to provide 1200 accommodations.
- Continue to educate the DoD community regarding disability management issues.
  - -- Targeted 40 presentations and workshops for FY 92.
- Streamline the procurement/request process for adaptive equipment.
  - -- Improve timeliness of accommodation delivery.
- Coordinate with DoD managers to ensure accommodation requirements are incorporated in system development.
  - -- Select representative systems under DMSSC authority and conduct review to ensure compatibility with adaptive equipment.
- Develop and conduct workshops regarding acquisition planning for accessibility.

- -- Mainstream accessibility requirements with on-going system hardware and software procurement.

- Serve as an accessibility requirements advisor to the Medical Functional Working Groups, Technical Integration Manager and Technical Implementation Managers of the DoD Corporate Information Management (CIM) initiative.

  - -- The CIM initiative centralizes DoD system and communications development activities.

  - -- Incorporate accessibility requirements in system requirements definition, design and development process.

Dinah F.B. Cohen, C.R.C.
Program Director
Computer/Electronic
Accommodations Program
DMSSC
5109 Leesburg Pike, Suite 502
Falls Church, VA 22041

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# SEATING THE ACUTE TRAUMATIC BRAIN INJURY CLIENT- A CASE STUDY

J. Piriano, P.T.; E. Cherwak, P.T.; B. Unruh*
A.R.T. Program, Marianjoy Rehabilitation Hospital and Clinics
The Durable Medical Equipment Shoppe, Naperville*

**ABSTRACT**
Traumatic Brain Injury (TBI) clients admitted to an in-patient acute rehabilitation setting present with a wide range of complex seating and mobility needs that must be addressed in an ongoing manner. A service delivery system established by the Applied Rehabilitation Technology (ART) Department to meet the changing needs of the TBI client is an essential component of the rehab team in order to maximize functional outcome. This case study will demonstrate the changing needs of the TBI client and the service delivery model established to meet these needs in a timely manner.

**BACKGROUND**
In response to M.D. orders to get the early acute TBI client out of bed and into a w/c, a number of clients have been admitted to our rehabilitation facility with a definitive w/c and seating system that has been funded by a 3rd party payor. Unfortunately, none of the systems were designed to change with the needs of the client, thus necessitating negotiation for new seating systems and mobility devices. This is not cost effective and it does not provide ongoing benefit to the client. Thus, it is essential that 3rd party payors and Rehab Technology Suppliers (RTS) understand the diagnosis of TBI and the changing needs of this diagnostic group.

**CASE STUDY-R**
R is a 15 year old male who sustained a Closed Head Injury secondary to a beating with pipes and bats by alleged gang members for his tennis shoes. He was found unconscious. CT-scan revealed cerebral edema, blood in the 4th ventricle, and hemorrhages near the occipital lobe. He was intubated, and had a gastrostomy tube placed. His course was complicated by pneumonia, grand mal seizures, GI bleed, and urinary tract infections. He was admitted 8 weeks post injury to our acute rehab center medically stable.

Upon admission R was evaluated by the rehab team and orders were received from the M.D. to get the patient up in a w/c. He was issued a narrow recliner w/c, a 16" x 18" Jay cushion, and a posey belt through the hospital, and a request was submitted to the ART department for evaluation of his seating needs. R was found to be dependent in head and trunk control, dependent in mobility, inconsistent in his responses to stimuli, and and unable to follow simple commands. Following assessment by the ART department R was seated in an 18" standard recliner w/c (seat to back angle at 120º) with a solid 1" drop seat platform, 16" x 18" Jay cushion, bilateral 1 1/2" hip blocks, 45º angle pelvic stabilizing belt, 18" Jay back with jumbo lateral trunk supports, adjustable height removable desk armrests, polycarbonite upper extremity support tray, medium Otto Bock head/neck rest with multi-axial hardware mounted to the Jay back, elevating legrests, and anti-tipping devices. He was able to tolerate this system for up to 3 hours, attend therapies in the clinic, and was consistently more alert, aware, and responsive than when in bed. As his tolerance to upright increased the seat to back angle was decreased to 110º then to 100º with the headrest changed accordingly.

R began demonstrating increased purposeful activity, and an inconsistent ability to follow 1 step commands. At this time he was reassessed by ART along with a local RTS present. The RTS provided a 16" Gunnel tilt-in-space and recline w/c with a firm back, lateral trunk supports, a 16"x 20" Jay cushion with a solid insert, 45º angle pelvic stabilizing belt, Otto Bock head/neck rest, adjustable height/adjustable angle removable armrests, swingaway footrests with heel loops, and anti-tipping devices for assessment. The tilt-in -space feature of this system allowed the team to begin to decrease his seat to back angle while utilizing gravity to assist and to maintain head and trunk control.

R's tracheostomy was plugged and eventually discontinued. He began to follow 1-2 step commands consistently, and when he could move his left upper and lower extremities in an isolated manner he began to learn w/c propulsion. His head and trunk control remained poor thus he continued to require external support and the assist of gravity therefore he was reassessed for a different seating and mobility system. The ART department, along with the local RTS seated R in a 16" lightweight recliner w/c with a 1" solid drop seat, 16" x 20" Jay cushion with bilateral hip guides, 45º angle pelvic stabilizing belt, 16" Jay back with large lateral trunk supports, medium Otto Bock head/neck rest, adjustable height, removable desk armrests, polycarbonate full upper extremity support tray, swingaway footrests with heel loops, and anti-tipping devices. He started to propel this chair with his left lower extremity with maximal assist. Wheelchair propulsion created a deterioration of his positioning thus the anterior portion of the solid seat was dropped 2", and back pack positioning straps were placed on the Jay back. R began to propel the w/c with standby assist with his left lower extremity and was beginning to use his right as well.

R was then reassessed by the ART department for a 16" ultralight wheelchair with no changes made to his seating system at this time. The wheelchair was oriented back in space 15º as R continued to present with poor neck and trunk extension. R tolerated the w/c and seating well and at this point it was determined that it was appropriate to order R's definitive w/c. R soon learned to propel the w/c with both lower extremities, both upper extremities, or with all 4 extremities. He was becoming adept at setting up the w/c for transfers, and was making cognitive, oral motor, fine and gross motor gains as well. His head control improved slowly. However, once he displayed sufficient and consistent control his headrest was removed. He began oral intake of food and liquids under supervision and soon his G-tube was discontinued.

R's trunk control continued to improve slowly, he was no longer required to be oriented back in space for oral feedings, was participating in his grooming, hygiene, and feeding skills, and was beginning to work on paper and pencil tasks. At this time the orientation of his chair in space was changed to 5º in space. Soon after the lateral trunk supports were moved away from close contact, and shortly after that they were removed altogether. R became proficient at w/c propulsion on level terrain, began propulsion on unlevel surfaces, was able to set the wheelchair up for transfers, performed grooming, hygiene, dressing, and feeding at the w/c level. He was unable to perform his activities of daily living without the external support provided by his w/c as he displayed severe ataxia in the trunk and upper extremities without the external support. As trunk control and functional mobility improved R's Jay back was removed and replaced by a 16" Jay Active back. This provided R with lumbar and low thoracic support without interfering with upper extremity and upper thoracic mobility.

R continues to utilize this w/c 1 year post injury with the exception of the polycarbonite upper extremity support tray. His trunk control has improved to fair/fair+, he is ambulating short distances with moderate assist using a cane, and is beginning to perform some of his activities of daily living out of his wheelchair. He still uses his w/c as his primary mode of mobility, and in the performance of the majority of his daily tasks.

The ability to change R's seating system and mobility device was made possible through the cooperative efforts of the Rehab team, the Applied Rehabilitation Technology Department, the local Rehab Technology Supplier, and the Third Party Paying Source. Had any one of these key members been inflexible or unwilling to meet the changing needs of this Traumatic Brain Injury Client the clients' maximal functional outcome may not be achieved as complications may have arisen secondary to poor seating and positioning. Complications such as musculo- skeletal deformity, respiratory gastro-intestinal, or bowel and bladder compromise would have significantly affected R's progress and thus his outcome.

It is imperative that all parties involved in the rehabilitation and the seating and mobility selection for the acute Traumatic Brain Injury Client be aware of the changing needs of this diagnostic group and strive to meet these needs in an efficient and timely manner in order to maximize the client's functional outcome.

**ACKNOWLEDGEMENTS**
Marianjoy Rehabilitation Hospital and Clinics (MRHC), in Wheaton, IL. provides a variety of levels of rehabilitation to inpatient and outpatient clients of all ages and disabilities. The Applied Rehabilitation Technology program at MRHC is an inter-disciplinary team which provides evaluation and training of various rehab technologies.

The DME Shoppe in Naperville, IL. is a full service rehabilitation technology supplier.

Julie A. Piriano, PT
Applied Rehab. Technology
Marianjoy Rehabilitation H&C
Box 795, Roosevelt Rd.
Wheaton, IL 60189

# Assistive Technology On Campus (ATOC): Preparation For Meaningful Careers

James A. Lenker
Center for Therapeutic Applications of Technology
University at Buffalo
Buffalo, NY

## ABSTRACT

The Assistive Technology on Campus program provides persons who have disabilities with assessments for adaptive devices and promotes the provision of appropriate educational experiences alongside their non-disabled peers. The program's overall goal is successful placement in long-term, mainstream career positions for persons with sensory, physical, or cognitive disabilities.

## BACKGROUND

Several articles have been written that summarize general issues for computing accessibility on college campuses [2], current efforts to increase accessibility of computers on college campuses [1], and exemplary technology support service programs on 16 university and college campuses [3].

The ATOC program was initiated in August 1990 for the purpose of investigating a model that would improve employment opportunities for graduating college students who have disabilities. The model includes improvement of service delivery and accessibility at three colleges representing the three traditional levels of post-secondary instruction: a four-year research university, a four-year state college, and a two-year community college.

Assistive devices and computer-based technologies are integral to this program because: 1) many students with disabilities can utilize technology to more fully participate in an integrated higher education environment, and 2) more and more positions in our job sector require computer skills and involve using or developing new technology.

## OBJECTIVES

ATOC's objectives include:

1. Identification and referral of post-secondary students who have disabilities to appropriate resources for assistive technology service delivery.

2. Provision of an integrated higher education experience for students with disabilities that will lead to a career placement. Specifically this includes:

a. Utilizing the services of a model regional center on assistive technology to provide students with equipment and training in the use of that equipment.

b. Working with the computer centers on the three campuses to make public computer centers accessible to students with disabilities.

c. Collaborating with the campus offices of disabled student services to provide additional advisement or guidance needed to support these students in an integrated higher educational environment.

d. Through a series of campus faculty orientations, increase faculty understanding and awareness of reasonable classroom accommodations and assistive technology.

3. Successful career placement. Specific objectives for achieving this goal are:

a. Working with college job placement officers from three campuses and members of an Employers Task Force on Disabled Persons to provide guidance and support in the selection of the first career job.

b. Utilizing the services of a model regional center on assistive technology to provide graduating students who have disabilities with any special equipment and training that may be necessary for successful job placement.

c. Providing employers with technical assistance needed on job modification and/or worksite accommodation.

c. Working with State agencies that support employment of persons with disabilities to provide funding for equipment and worksite modifications required for the first career job.

## METHODS/APPROACH

Individual student referrals typically originate from three sources:

1. One of the state vocational rehabilitation agencies.
2. The appropriate office for disabled student services.
3. Self-referral.

In all cases, the appropriate vocational counselor is contacted and an appointment for service is made. Use of a regional center for rehabilitation technology services is invaluable for the device assessment and training phases.

Networking with the Collegiate Consortium for Disability Awareness (C.C.D.A.), has helped facilitate many of ATOC's working relationships. Members of the C.C.D.A. include representatives from over fifteen area campuses, as well as the New York State Office for Vocational and Educational Services for Individuals with Disabilities and the New York State Office for the Blind and Visually Handicapped.

In addition, ATOC has been an active participant in a local employment consortium that includes representatives from over 30 placement agencies.

RESULTS

The individual accomplishments of ATOC to date reflect its use and coordination of existing resources to achieve the broader mission of improving the post-secondary experience and increasing the probability of eventual employment of college students who have disabilities.

Transition into post-secondary education
ATOC is sponsoring a half-day conference for the purpose of advising special educators, resource room instructors, and administrators about issues for students who are transitioning from high school to one of the local post-secondary institutions. This conference will be taking place in May 1992. A "Students/Parents Night" will be sponsored in Fall 1992 for the purpose of educating transitioning students and their families about the requirements for entering post-secondary institutions in the region. A third transition-oriented conference will be sponsored in Fall 1992 for the purpose of advising special education instructors and their administrators about the potential applications of assistive technology in the classroom.

Assistive technology service delivery
ATOC is working in cooperation with the New York State Office of Vocational and Educational Services for Individuals with Disabilities, the New York State Commission for the Blind and Visually Handicapped, and a regional center for assistive technology assessment and training. ATOC has already worked intensively with over 40 individual students. The type of assistance provided has included assessment, recommendation, installation and training for use of computer equipment, wheelchair seating and positioning,and architectural access issues.

Improvement of campus accessibility
ATOC has provided assistance to the participating community college to upgrade its computer facilities to include hardware and software for improving access to those with limited vision and/or physical impairments. Installation of hardware and software, as well as development of training materials, will be coordinated by ATOC in conjunction with computer support staff at the community college. The philosophy behind this particular effort is being guided by the suggestions for facilities accessibility, staff training, and equipment flexibility suggested by Berliss and Vanderheiden [2].

The Collegiate Consortium for Disability Awareness will provide their opinions of campus accessibility for deaf and hard of hearing students. Technological devices as suggested by Seelman [4] will be considered for recommendation and/or purchase.

Five existing programs listed by Berliss [1] are being contacted for information about their experiences in accessible computing, as well as the "Centers of Energy" report being compiled by California State University, Northridge [3].

With input from the local Collegiate Consortium for Disability Awareness, ATOC is compiling education materials for the purpose of developing a faculty training module that will educate faculty about their responsibilities for accommodating students who have disabilities. Presentations will begin to individual department meetings at the beginning of school year 1992.

Transition into the workplace
ATOC will be assisting with presentation and advertisement of a free, half-day conference in April 1992 for disabled college students who are preparing to graduate. Topics included will be: implications of the ADA, applications of assistive technology in the workplace, and a roundtable discussion of disabled graduates who will reflect on their experiences in the workplace.

DISCUSSION

ATOC's program goals are very ambitious, but so far it is making successful inroads on all issues. Further reporting and analysis of results will be published at the conclusion of Year 3 (August 1993).

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James A. Lenker
ATOC Project Director
Center for Therapeutic Applications of Technology
University at Buffalo
515 Kimball Tower
Buffalo, NY 14214

# AN ANALYSIS OF THE ROLE OF INDIVIDUALS WITH DISABILITIES IN COMPUTER-RELATED PROFESSIONS

Daniel K. Davies, Randy W. Dipner, and Robert H. Gattis, Jr.

Meeting the Challenge, Inc.
Colorado Springs, CO

## ABSTRACT

The purpose of this study was to investigate the role of individuals with disabilities in the computing professions through a survey of the Association for Computing Machinery (ACM). ACM is one of the largest organizations of professionals in the computing industry with a total membership of over 80,000. Surveying this membership contributes to the growing body of data to address the magnitude of disability in the science and engineering industry. This survey will help determine 1) the percentage of members who have some form of disability, 2) the adequacy of disability accommodations in the workplace, and 3) ACM's need to provide special accommodations for individuals with disabilities. The results of this study will help ACM continue to provide quality service to all of its members. In addition, ACM's proactive effort to understand the breadth of disability among its members is setting the pace for other professional organizations.

## BACKGROUND

Recent surveys on the prevalence of individuals with physical, mental, or emotional disabilities in the general United States population have estimated that the number of individuals with some form of disability is quite significant. For example, the National Institute on Disability and Rehabilitation Research (NIDRR) reports that when disability is categorized as a limitation in the ability to perform selected physical functions, more than 20% of all non-institutionalized people over the age of 15 have a disability (1). This amounts to over 37 million individuals. Additionally, the Americans with Disabilities Act of 1990 (ADA) indicates that "some 43,000,000 Americans have one or more physical or mental disabilities, and this number is increasing as the population as a whole is growing older" (2).

The National Science Foundation Task Force on Persons with Disabilities (3) reports that of the 5 million scientists and engineers in the U.S., at least 2% have disabilities. The Task Force also reported that of "experienced" scientists and engineers (i.e. individuals who reported a science or engineering profession as of the 1980 census), the number of individuals with disabilities ranges from roughly 2% to 16%. The method in which the question of disability is addressed and the definition of disability appears to affect the findings. For example, the Task Force noted that the lower estimate (2 percent) was obtained when the survey participants were asked if they had a physical disability, and if so, to identify the nature of the disability. The upper estimate was obtained when respondents were asked to indicate the degree of difficulty they had in seeing, hearing and walking and to what extent those functional limitations impacted their education, employment, and career.

A major issue highlighted by the Task Force is the need for accurate data on the existence of disability. The following is an excerpt from the Task Force's report:

> As federal, state, and local government agency officials begin enforcing the Americans with Disabilities Act (ADA), it will become all too apparent that there are no consistent data available about Americans with disabilities and no accepted definition(s) of key concepts, including that of "disability." Data must be collected about persons with disabilities' participation in the educational systems (including degrees earned data), in employment, and in a wide variety of similar areas. Only after these problems have been addressed will the magnitude ... of the problems that led to the enactment of the ADA become known with any precision. (p. A-1)

### *The importance of the ADA*

On August 26, 1990 the ADA was signed into law. This act represents the most far-reaching civil rights legislation since the Civil Rights Act of 1964. In essence the act states that organizations may not discriminate against individuals with disabilities. Further it states that they must make reasonable accommodation for individuals with disability.

The primary relevance of the ADA to professional organizations such as ACM is in the area of disability accommodation. The ADA requires service organizations to not discriminate against individuals with disabilities in the service they provide and requires that "reasonable accommodation" be made to provide comparable services to these individuals. A first step in servicing this population is understanding the numbers and types of disability represented in the professional membership.

### *Defining disability*

Traditionally, attempts to estimate the prevalence of disability have been difficult. One reason is that there is no universally accepted definition of disability. Without a common understanding, comparing results from one survey to another has been difficult. The National Council on Disability, in its 1988 report entitled *On the Threshold of Independence*, states that most surveys on disability have focused on one of two approaches: the health condition approach which targets conditions or limitations that impair normal functioning in some way, or the work disability approach which examines conditions which limit or prevent a person from working (4).

An approach used in a survey by Louis Harris & Associates (5) added a third criteria to these two definitions of disability. This approach was based on whether or not the individuals considered that they had a disability or whether the individuals believed that others would consider them to have a disability. The National Council on Disability proposed that the approach used in the Harris survey provides a conceptual model for developing more adequate instruments for surveying disability. This model (modified appropriately to apply to the ACM population) has been employed in this study.

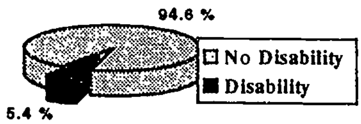
## METHOD

An initial test survey was developed and mailed to ACM's Mountain region (n=400). The survey and procedures were revised based upon the test results and further review by experts from ACM, the National Science Foundation, the National Council on Disability, and other organizations. Following completion of the survey instrument, a random sample from the entire U.S. membership was selected. A total of 7,977 surveys were mailed out to members of ACM in July 1991. Surveys were mailed out as a 8 1/2" X 14" double-sided survey form. When folded, the survey formed a return envelope with return address and return postage provided.

## RESULTS

A total of 1,838 surveys were returned between August and December 1991 for an overall response rate of 23%. In summary, a total of 96 or 5.4% (+/- 1%; $p<.05$) of the respondents self-identified as having a disability (Figure 1). Self-identification of disability was cross-validated by

Figure 1: Individuals with a Disability in the ACM Membership




reviewing responses to the ability related questions on the survey. Respondents were requested to provide basic demographic information in the first section of the survey. The next section addressed basic abilities such as use of computers, verbal and written communication, and various physical tasks. This section was followed by an evaluation of workplace accommodations and identification of assistive technology products in use. Finally, respondents indicated what accommodations would be useful to them for ACM publications and conferences. An overview of the results is provided in the following paragraphs. Values represent valid percentages for all returned surveys. The demographic data represents only the subset of respondents with a disability (n=96). The sections on workplace accommodations, assistive technology in use, and useful accommodations for ACM represent the entire set of survey respondents (n=1,838).

### *Demographic summary*

Demographic data were requested from all respondents in the first part of the survey. The results depicted in Figures 2 through Figure 5 and Table 1 represent demographics for the subset of respondents with a disability.

Figure 2: Gender

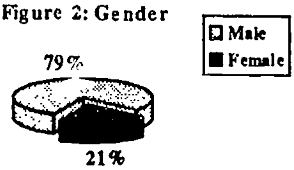



Figure 3: Age

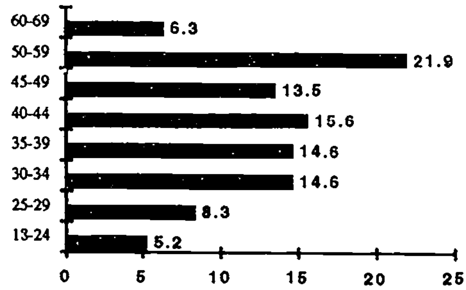



Figure 4: Highest Degree

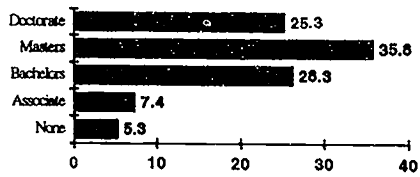



Figure 5: Employment Status

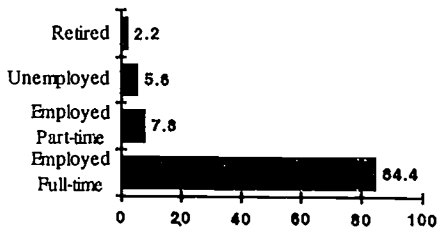


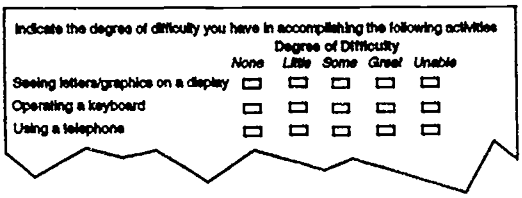

Table 1: Race/ Ethnicity of Population

| Race/ Ethnicity | % |
|---|---|
| Asian/ Pacific Islander | 3.2 |
| White Hispanic | 1.1 |
| Black Hispanic | 0 |
| White | 94.6 |
| Black | 0 |
| Native American/ Alaskan Native | 0 |
| Other | 1.1 |

*Ability to perform basic activities*

Respondents were asked to indicate the degree of difficulty in accomplishing a variety of basic activities, with an emphasis on computer-related tasks. Ratings were based on a Likert type scale with value labels indicating the degree of difficulty the respondent had in performing each activity (see Figure 6). This information was used to cross-validate the prevalence of disability for those who indicated having a disability.

**Figure 6: Ability Rating Scale**




*Accommodations in the workplace*

Respondents were asked to identify the facility modifications/ accommodations available at their office or school. For each item, respondents rated whether, in their own opinion, the accommodations were adequate or not. Additionally, respondents had the option to indicate if the accommodation was unavailable or unknown. Table 2 summarizes the responses to this section.

**Table 2: Facility Modifications/ Accommodations**

| Accommodation | % A | % I | % U | % ? |
|---|---|---|---|---|
| Building Access | 77.3 | 11.5 | 7.2 | 4.0 |
| Facility Entry | 47.1 | 30.0 | 17.3 | 5.6 |
| Bathroom Adaptation | 63.7 | 18.8 | 12.7 | 4.8 |
| Braille Signs | 43.6 | 11.5 | 27.5 | 17.4 |
| Elevators | 69.2 | 8.5 | 8.7 | 4.4 |
| Public TDD | 7.8 | 7.7 | 33.3 | 51.2 |

A = Adequate I = Inadequate
U = Unavailable ? = Unknown

*Assistive devices in use at work or school*

Respondents were asked to identify what assistive technology devices are in use at their office or school and whether the device was individually owned or employer provided. Table 3 provides a summary of the responses to this question.

**Table 3: Assistive Technology Devices in Use**

| Assistive Device | % E | % I | % N | % ? |
|---|---|---|---|---|
| Wheelchairs/ mobility | 5.7 | 32.1 | 33.1 | 28.9 |
| Telephone adaptations | 14.4 | 4.0 | 31.6 | 49.9 |
| Adapted keyboard | 8.6 | 2.3 | 43.1 | 45.9 |
| Voice input technology | 4.9 | 1.5 | 50.1 | 43.4 |
| Synthesized speech | 7.3 | 2.4 | 48.0 | 42.3 |
| Text scanners | 7.9 | 1.7 | 44.5 | 45.9 |
| Other | | | | |

E = Employer provided I = Individually owned
N = None available ? = Unknown

*Accommodations useful for literature and conferences*

All respondents were asked to indicate what accommodations would be useful to them for ACM literature/ correspondence and conferences/ meetings. Please note that all respondents were asked this question, not just those indicating a disability. Table 4 provides the results.

**Table 4: Accommodations Useful to ACM Members**

| Useful for ACM literature/ correspondence | % |
|---|---|
| Braille copy | 1.5 |
| Audio tapes | 7.1 |
| Electronic media | 27.0 |
| Other | 2.3 |
| **Useful at ACM conferences and meetings** | **%** |
| Facility access | 4.1 |
| Bathroom adaptation | 2.7 |
| Subtitled closed caption TV | 3.4 |
| Sign language interpreter | 1.5 |
| Telecommunication Device for the Deaf | 1.2 |
| Other | 1.6 |

## SUMMARY

The results of this survey provide further insight into the role that individuals with disabilities play in the scientific and engineering communities. Additionally, this report provides some insight into the types of accommodations available in the workplace and the perceived adequacy of those accommodations. Computer technology offers exciting potential for aiding individuals with disabilities and narrowing the gap between inability and independence. Computing professionals can play an important role in the development of high technology solutions to enable individuals with disabilities to reach their highest level of personal independence and professional accomplishment.

## ACKNOWLEDGMENTS

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Daniel K. Davies
Meeting the Challenge, Inc.
3630 Sinton Road , Suite 103
Colorado Springs, CO 80907

P2.8

# PUBLIC SPENDING ON ASSISTIVE DEVICES IN DIFFERENT COUNTRIES

Gunnar Fagerberg
INROADS, London, Ontario

## ABSTRACT

The paper relates data on the public spending on assistive technology in different countries. A comparison is made between Ontario and Sweden.

## BACKGROUND

A few attempts have been made to compile information on service delivery systems for assistive devices from different countries and regions of the world (1,2). Financial information has sometimes been included in the data presented. However, comparisons are difficult to make because terminology, definitions, environment, culture, political systems and socio-economic factors vary significantly between the entities studied.

At recent workshops organised by United Nations Economic and Social Council, Economic Commission for Europe (UN-ECE), information on service delivery programs was presented by representatives from different countries.

## OBJECTIVE

Many countries in the industrialised world have established public funding programs for assistive technology. In some countries, public funding accounts for almost 100% of the total spending on assistive devices. In others, other sources, such as private insurance, consumers own purchases and charity organisations, cover a substantial portion. Public funding is frequently provided from several sources on national, regional (provincial) and municipal levels.

Given these differences, the information reported at the UN-ECE workshops of spending, public and other, on assistive technology can give a rough indication of the size of the market and the level of use of assistive devices in rehabilitation of persons with disabilities in different countries.

## METHOD AND RESULTS

For this compilation, the data presented at the two workshops arranged by UN-ECE, complemented with some data from other sources, were used. The total spending figures reported were divided by the population of the respective countries. Thus, the resulting number indicates the amount per inhabitant spent on assistive technology.

| Year | Country | Population (millions) | Annual spending (mill US$) | Spending/ inhab. (US$) |
|---|---|---|---|---|
| 1990 | Denmark | 8.4 | 302 | 60 |
| 1988 | Finland | 5.0 | 61 | 12 |
| 1991 | Hungary | 10 | 51 | 5 |
| 1989 | Japan | 122 | 74 | 0.6 |
| 1988 | Norway | 4.2 | 218 | 52 |
| 1990 | Ontario | 9 | 72 | 8 |
| 1990 | Slovenia | 2 | 10 | 5 |
| 1989 | Sweden | 8.4 | 591 | 70 |

It is obvious that a straight comparison can not be made based on these figures. The following comments will illustrate why.

Denmark: "There is no statistical material of the total use of technical aids, but this figure is the closest guess we can come up with." (3)
Finland: Schools and insurance companies are not included. (4)
Hungary: On average, 90% of the cost is covered by the government. (5)
Japan: Figures from two out of ten different programs. Japan reports that persons with disabilities make up 2% of the population, significantly lower than other industrialized countries. (6)
Norway: Includes "cars & special appliances" and "appliances for special care". (7)
Ontario: The program covers 75% of the cost of the device. Some device categories are funded only for persons under 27 years of age. (8)
Slovenia: 1% of total health spending is estimated to go towards assistive devices. (9)
Sweden: Includes home adaptations, car subsidies, "cost-free supplies", worksite adaptations and TDD's. (10)

In order to make any comparison between countries, it is necessary to study much more in depth what is included in the reported figures and limit the comparison to those categories of devices that are compatible statistically.

Such data are available for Sweden and the province of Ontario, Canada (8,10). The two are also similar in many respects such as population (8-9 million), climate, lifestyle, health factors and national health insurance.

In Sweden, a system of total coverage of costs for assistive devices was introduced in 1968. The devices are provided through the health system and are paid for by the county councils, who in turn receive about 50% coverage from the national government.

In Ontario, the Assistive Devices Program was established in 1982, originally to provide assistive devices for children (up to 19 years of age). Since then, the program has expanded to cover many categories of devices for all age groups. The program pays for 75% of the cost of prescribed equipment, while the client pays 25%. Sometimes, the client portion can be covered by insurance or voluntary organizations.

The two programs have similarities and differences. Both are based on a system of authorized prescribers and lists of approved equipment. Some device categories are more strictly regulated than others.

Why is it then, that the Swedish program cost the equivalent of CAN$ 440 million (not including home and worksite adaptations or car subsidies) and the Ontario program only CAN$ 84 million (same exclusions), even if the latter only covered 75% of the total cost? What did persons with disabilities in Sweden receive that Ontarians did not?

First, let's look at some of the more glaring differences. In Sweden, no less than $159 million covered so called "cost-free supplies" which is supplies for incontinence, ostomy and diabetes. The total for incontinence and ostomy in Ontario (diabetes supplies are not covered) is only $9 million. The main reason for this discrepancy is that in Ontario, incontinence supplies are only covered for persons born 1963 and later, while the vast majority of Swedish clients in this category are elderly.

Another area of difference is orthotics, where Ontario reports a cost of $3.5 million and Sweden $54 million. However, about half of the Swedish figure represents orthopedic footwear and the other half includes orthoses for athletic injuries, prophylactic purposes and fracture treatment. More difficult to explain is the gap in spending on prosthetics (Sweden $29 million, Ontario $ 9 million), visual aids (Sweden $12 million, Ontario 0.6) and mobility/seating (Sweden $27 million, Ontario $3.6 million). The Swedish program also covers some categories that the Ontario program does not: ADL devices, environmental controls, signalling and listening devices and some devices for therapy and training. By tradition, the Swedish program also includes pacemakers and sign language interpreters.

On the other hand, the Ontario program covers respiratory equipment and supplies to a much larger extent than does the Swedish program.

Finally, there are two categories where the reported spending is very similar. For hearing aids, Sweden spends $30 million and Ontario $21 million. Considering that Ontario covers 75%, the total amount spent is almost identical. The same is nearly true for wheelchairs, where the Swedish figure is $44 million and the Ontario program spends $28 million.

It is also interesting to note that the growth of the Ontario ADP program has been very rapid between its start in 1982 and 1990 (an annual increase by 70%), very similar to the development of the Swedish program over its first ten years. After that period, the growth rate in Sweden has decreased, but is still higher than the inflation. From 1982 to 11988, the Swedish costs increased on average 13% per year (11).

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Gunnar Fagerberg
INROADS
The University of Western Ontario
Faculty of Applied Health Sciences
Elborn College
London, Ontario
CANADA N6G 1H1

P2.9

# Training Experiences for Rehabilitation Engineering Students

Thomas L. Grey
Assistive Device Center, CSU Sacramento

Abstract

This paper describes the design and implementation of formal training experiences for rehabilitation engineering students in assistive technology service delivery. The design, structure and effectiveness of the experiences to date are discussed. Implications for service delivery organizations that are considering the provision of similar experiences for rehabilitation engineering students are presented. These activities may also help to more clearly define the role of an engineer in assistive technology service delivery.

## Background

A formal training program for rehabilitation engineers is now in its second year of development and implementation. Students participate in formal coursework leading to a Master's degree in Biomedical Engineering with a certificate in Rehabilitation Engineering. This coursework is supplemented with additional experiences - students spend about 10-15 hours per week on these - in the areas of rehabilitation research (two semesters), assistive technology service delivery (two semesters), and formal internship (under an engineer's supervision) with a company or organization involved with assistive or rehabilitation technology (summer or winter intersession). This paper is discusses training experiences that the students receive in assistive technology service delivery at a service delivery center affiliated with the training program.

## Design and Structure

The goal of the training activities at the service center was to provide each student with the experience necessary to become an effective member of an assistive technology service delivery team after graduation. The program faculty and service center staff determined that this experience should include training and practice in the areas of assistive technology (working knowledge of devices), assessment, report writing, funding, implementation (ordering, setup, delivery), training and follow-up. This would be accomplished during two rotations through the service center during different semesters in order to accommodate the variety of training and practice activities and the limited amount of time the students are scheduled to participate (10-15 hours/week). All activities are carried out under the supervision of one of the service center's two engineers.

During the first rotation, the students learn about the assessment process by reading specific literature, observing client assessments, and participating in team meetings. The students interview each member of the service center staff (Speech Pathologists, Occupational Therapists, Engineers, Funding Specialist, Clerical Support) to understand that person's perspective and role regarding the service delivery process. Formal training modules on seating and mobility, augmentative and alternative communication, and system mounting are completed to provide a working knowledge of devices. Students participate in the ordering and setup process for funded client systems. Direct client interaction is introduced by having students assist the team during deliveries and training. Beginning this spring, first rotation students will also engage in more formal follow-up activities (phone interviews with clients, formal presentation of information/recommendations to the client's team) and will complete a small technical project for the service center's internal use. These activities are intended to provide the students with enough background to take full advantage of a formal internship at a different site.

The second rotation students take increasing responsibilities for clients. They begin by reviewing the assessment process, sitting in during client assessments, participating in report research and writing, and assisting with equipment deliveries and training. The students gradually assume greater responsibilities from the team engineer for assessments and deliveries. Toward the end of the rotation, the students assume full responsibility for a full client assessment (and delivery if possible) with the service center team engineer providing a supportive role. This process is intended to provide second rotation students with experiences and responsibilities that will increase their competence and confidence.

## Conclusions

It is not yet possible to fully measure the effectiveness of this approach to training experiences for rehabilitation engineering students. This is because the first students to enter the program have yet to graduate, let alone obtain a position as a rehabilitation engineer. The "real world" usefulness of this training is the best measure of its effectiveness. The subjective opinion of the author is that the students could benefit from more direct supervision than has been possible to date. Also, direct client interaction has been sporadic due in part to the service center's service delivery structure and in part to decreased funding levels. Student evaluations have identified better planning for student experiences and increased contact with an engineer as areas of concern, but have otherwise rated the experience as useful and enlightening.

The provision of training experiences to rehabilitation engineering students has proven to be quite challenging. Experience is indicating that supervision of a single student in the first rotation working 10 hours requires at least 2 hours per week. A second rotation student working 10 hours per week also requires at least 1 hour of direct supervision with 1-3 additional hours for support (e.g., providing direction, discussion of ideas, etc.). An attempt has been made to spread this supervision among team members, but student feedback indicates that the students find direct interaction with another engineer most helpful because other team members typically cannot provide enough technical assistance and input.

Organizations interested in providing students with similar experiences must be willing to let their staff engineer(s) have the time needed to effectively supervise the student and act as mentor, perhaps at the expense of other activities. Advanced planning is needed in order to seamlessly integrate the student into the organization and out of the organization when the training experience has ended (e.g., completing a project before leaving is very important). In order to be effective, the anticipated training experiences must be able to provide problem identification, analysis and solution design as well as writing experiences and opportunities to directly interact with clients/customers. These latter experiences help develop the engineering student's communication skills - something that engineers are notoriously noted for not having.

The benefits can be great. The planning needed to work with a student often leads to introspection within the organization, which may identify areas that can be improved (perhaps by having the student accomplish certain improvement tasks). The organization can benefit from having additional engineering expertise to assist in client system design and delivery (not to mention someone who may be able to tackle some of those back-burner projects!). Moreover, the participating engineer can benefit significantly from students' questions, which often challenge the way that the engineer approaches problems and designs solutions. This can provide fresh insight and better, more cost-effective solutions. In the long run - and most of all - these experiences can improve the provision and outcome of services by making the practicing engineer better at her/his craft and the entry-level engineer more competent in her/his first position.

Thomas L. Grey, M.S.
Assistive Device Center
Rehab. Engineering Training Program
School of Engineering and Computer Science
California State University, Sacramento
6000 J Street
Sacramento, CA 95819

P2.10

# Educating the Case Manager: An Essential Component to Rehab. Technology Service Delivery

C. Sargent, R.E.; E. Cherwak, P.T.; J. Piriano, P.T.; R. Brooks*
A.R.T. Program, Marianjoy Rehabilitation Hospital & Clinics
The Durable Equipment Shoppe, Naperville*

**Abstract:**

The Applied Rehab. Technology (A.R.T.) program and a local rehab. technology supplier (RTS) provided a half day workshop to a professional organization of case managers. The purpose was to increase the understanding of rehab. technology equipment, e.g. its applications, and its relevance to the rehab. process. The goal was to educate case management representatives of rehab. technology's value to their client and cost containment efforts.

**Background:**

In the ongoing effort to contain the costs of medical care, many commercial insurers have begun to utilize case managers to allocate resources for the costs incurred by their clients. In the case of rehabilitative health care, costs for rehabilitation technology equipment must be considered as well, often during the inpatient phase of treatment.

The procedure of the A.R.T. program is to evaluate a patient (client) for his/her equipment needs and whenever feasible, to fit him/her with the type of equipment which is recommended for trial use, training and assessment. Following establishment of the definitive equipment needs, contact is made with the case manager to communicate the client's individual equipment needs, identify the client's coverage and determine if preferred providers are to be used. The primary rehab. technology specialist from the A.R.T. program prepares a comprehensive letter of medical necessity justifying the recommended equipment, and obtains the primary physician's signature. A copy of this letter is often mailed or faxed to the case manager for review. In some instances the case manager will pursue price quotes prior to identification of an RTS, and authorization of the equipment order.

A common occurrence in the process of obtaining a patient's equipment has been the need to verbally explain the recommended equipment item by item, despite the lengthy written justifications (and occasionally photos) which are incorporated into the letter of medical necessity. Additionally, the costs of the more complex systems and the potential for substitution are questioned, and occasionally are denied in the first round. A.R.T. program staff, and the RTS's with whom they work have had such interactions with case managers repeatedly. As appropriate equipment can be integral to successful rehabilitation, and be beneficial to overall cost containment, it is essential to educate the case manager.

**Method:**

The sales manager of a local RTS initiated plans for education and training of case managers in the Illinois Case Management Network, following identification and discussion of the need by all parties.

The educational workshop was scheduled for a half day to include three sessions. One session addressed seating and positioning techniques, and the types of intervention (or maintenance) strategies which could be utilized. A second session focused on power mobility devices, including scooters, and considerations for selection. The third session provided an overview on home access options. Slides were used to present three actual case studies of seating system interventions used to: prevent, correct and accommodate physical deformity. Approximately 25 case managers attended.

The presentations were made by teams composed of members of the A.R.T. program and RTS staff and included functional, clinical and product-specific information. All presenters communicated a common objective: clarification of rehabilitation technology applications. Emphasis was placed on the potential for properly fitted equipment to facilitate independence and enhance health maintenance. For example, specific products with pressure-relieving properties were reviewed.

The workshop was held at the RTS site, a facility with significant product and parts inventory and maintenance support staff. The significance of this environment was perhaps its parallel to the auto garage, a facility familiar to most as essential to the reliability and longevity of vehicles. This environment challenged the myth that a "wheelchair is a wheelchair, isn't it?". It also presented the opportunity for the case managers to try different devices and ask specific questions related to product features, maintenance and cost.

**Conclusions:**

Case managers in attendance indicated that the workshop provided information applicable to their task of allocating resources, and for supporting their approval decisions to the insurance companies they represent. Increased understanding of the roles of clinical rehab. technology specialists and RTS's was expressed.

**Future Plans:**

Education of case management representatives is vital to developing an understanding of rehab. technology equipment, its applications and its successful acquisition for the consumer. The A.R.T. program staff plans to pursue opportunities for joint workshops. Case managers will also be invited to visit inpatients so that recommended equipment can be demonstrated, and features described by clinician and consumer. Video taped demonstrations are under consideration as a means to reach case managers outside the local region.

**Acknowledgements:**

Marianjoy Rehabilitation Hospital and Clinics(MRHC) in Wheaton IL, provide a variety of levels of rehabilitation to inpatient and outpatient consumers of all ages and disabilities. The Applied Rehab. Technology program at MRHC is an interdisciplinary team which provides evaluation, training and equipment procurement advocacy for rehab. technologies.

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Carol A. Sargent,R.E.,OTR
Director, Applied Rehab. Technology
Marianjoy Rehabilitation H & C
Box 795, Roosevelt Road
Wheaton, IL 60189

# Computers in the Management of Assistive Technology Service Delivery A Call for Standardization of Data Presentation from Assistive Technology Manufacturers and Providers.

Nigel Shapcott, James A. Lenker & Margaret Strassheim
Center for Therapeutic Applications of Technology
University at Buffalo, Buffalo, NY

## ABSTRACT

An argument is presented for the development of defined processes, terminology and definitions in the delivery of Assistive Technology, along with standardized display, or standardized ASCII availability of catalogue data in order to automate data collection of devices.

## BACKGROUND

Modern businesses in Europe, North America and many other countries, rely on computers to expedite marketing/sales, purchasing, accounting, and inventory functions. Computers are ideal for repetitive, predictable tasks and enable huge amounts of information to be efficiently managed.
The primary goal of an effective automated system is its built-in capacity to adapt universal business functions to specific products and services. Analytical processes that can identify and streamline service delivery will impact cost containment, personnel, and equipment performance.

## OBJECTIVE

Assistive Tedhnology intervention is often assumed to involve "unique solutions". Providing "unique solutions" to "unique problems" is often assumed to preclude the use of a computer designed for repetitive, predictable tasks. Our objective has been to systematically analyze the components involved in Assistive Technology service delivery and computerize this process to assist in the delivery of these services? In doing so we have identified ares of policy (information presentation) which need to be improved.

## METHOD

As providers of Assistive Technology in Seating, Positioning, and Mobility we initially examined the process generated by a client upon entering a service delivery system prior to being presented with their intervention. The components of the process followed a logical sequence, providing a foundation toward developing a comprehensive relational data base. With definition of the process comes consistency and with consistency comes the ability to:

-streamline client intake procedures and provide a uniform basis for equipment and service determinations.
-accurately predict the equipment, labor, administrative & assessment costs.
-enable timely and concise communication with third party payors and governmental/ community funding sources
-increase productivity by decreasing client processing time
-quantify operational and fiscal reporting
-examine and improve services and procedures
-effective data collection for program review and research purposes

Our system utilizes a computerized relational data base to integrate client service from inception to delivery. A format of data collection was identified following standard procedures that is reflected on the data base.

**Demographics**-General information such as; name, address, date of birth, age, sex, diagnosis, and service requested.

**Evaluation**-Determination of appropriate form of service delivery.

**Scheduling**-Date, time, and personnel initiating service.

**Reports**-Individual or team approach to problem solving.

**Prescription**-Intervention and cost required to address client's needs.

**Funding**-Prior approval requests in specified funding source formats.

**Purchasing**-Manufacturer, cost, size, and amounts.

**Service Delivery**-Client/staff coordination, fitting time, client confirmation, and ongoing maintenance.

**Invoicing**-Cost summary and accounts payable/receivable.

**Case Management**-Provides detailed report to reflect service-to-date.

**Fitting time/cost**- manufacturer etc. approximately 2500 records.

Organization of data
Seating support surfaces and components are grouped by their function and indexed by description, the simplistic group codes used, follow:

A Armrest and tray
B Back, lateral and thoracic supports
C Control, switches, joysticks
E Evaluation procedures
F Foot, lower leg supports
H Head supports
I Interfaces
M Total contact supports, eg Matrix
O Other systems
R Seat belts, straps, "Restraints"
S Seats, cushions
W Wheeled base

Once a component of the system to be prescribed has been identified, a local # is all that is required to list that item with as much information as is required for the Prescription or ordering information. See Figures 1. 2 &3. This enables completely consistent data handling with no fudging.

## RESULTS

This system automates time consuming aspects of the prescription process and encourages accurate recording mechanisms (which is vitally important to identify causal variables effecting service delivery that may be attributed to one or all of the following factors; equipment delivery, prior approvals, or personnel availability).

Because third party payers are not familiar with the wide range of equipment prescribed, we are contemplating including a descriptive narrative of the item with the additional option of a line drawing. This would enable a description sheet to be automatically generated.

## DISCUSSION

This system depends upon a current and accurate data base of information for equipment. Presently this information has to be entered by keyboard, which is time consuming, costly and often inaccurate. Information provided by manufacturers is tantalizingly close to some form of automated entry, either by optical scanning or by direct input of ASCII files. Automation of this process would ensure accuracy and further enhance the system.

With the evolution of computer systems to expedite Assistive Technology service delivery, the lack of terminology, definitions, illustrations, and equipment standardization becomes increasingly apparent. The impact created by this void deters product comparison and challenges researchers attempting to develop or improve equipment. The term "reinventing the wheel" finds definition in clinics throughout our country.

The increase in clients being serviced with technological advances has produced a need for a new "model" upon which to pattern our clinics. The blending of professions and disciplines necessitates new standards of research, education, service, equipment, and review. We draw on the knowledge, skills, and abilities of medicine, engineering, and business; in each of these disciplines standards and practices have long been established.

## CONCLUSIONS

1. There is a need to broaden the ongoing work on terminology, to include clear definitions and pictorial information, where appropriate. This

should not be used to limit the development of equipment or the improvement of techniques.

2. The ability to compare information readily is of vital importance in the prescription process. There is a need to establish standards for listing of information in catalogues in order that information manufacturers information can be entered automatically.

3. It is possible to develop a relational database that effectively defines the service delivery process.

The practical adoption and application of these steps toward standardization will serve the needs of both client and provider, and must, by design, not be limited by standardization. The "unique solutions" to "unique problems" can only benefit and grow with established guidelines.

## ACKNOWLEDGEMENTS

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Nigel Shapcott, CTAT,University at Buffalo, 515 Kimball Tower, Buffalo, NY 14214

**Fig. 1** **Prescription and Cost Itemization**

| Code | Item Description | Size | # | Cost/each | Cost |
|---|---|---|---|---|---|
| 187 | Memphis Back kit | adult | | $793 00 | $793.00 |
| 1167 | Thoracic bracket | large 11" | 2 | $9.80 | $19.60 |
| 317 | Thoracic pad | large | 2 | $67 10 | $134 20 |
| 437 | Bead In Box Seat | 20w x19L | | $1176.25 | $1176.25 |
| 1425 | Black Vinyl | 30" x 36" | | $16 80 | $16 80 |
| 233 | Seatbelt | 1-1/2" wide. push button release | | $45 50 | $45.50 |
| 438 | Roho Insert | 6x10 | | $401 00 | $401 00 |
| 1950 | Head/Neck Support Fixure | single axis offset | | $59 65 | $59 65 |
| 359 | Headrest | 3 | | $126 25 | $126 25 |

**Fig. 2** **MediCaid Prescription and Cost Itemization**

| Code | Item Description | Price | Labor | Time | # | Cost/each | Cost |
|---|---|---|---|---|---|---|---|
| 187 | Memphis Back kit | 308 00 | 485 00 | 12 25 | | $793 00 | $793 00 |
| 1167 | Thoracic bracket | 9 80 | 0 00 | 0 00 | 2 | $9.80 | $19.60 |
| 317 | Thoracic pad | 19 60 | 47 50 | 1 00 | 2 | $67 10 | $134 20 |
| 437 | Bead In Box Seat | 490 00 | 686 25 | 18.00 | | $1176.25 | $1176.25 |
| 1425 | Black Vinyl | 16 80 | 0 00 | 0 00 | | $16 80 | $16 80 |
| 233 | Seatbelt | 28 00 | 17 50 | 0 50 | | $45 50 | $45 50 |
| 438 | Roho Insert | 266 00 | 135 00 | 3 50 | | $401 00 | $401 00 |
| 1950 | Head/Neck Support Fixure | 59 65 | 0 00 | 0 00 | | $59 65 | $59 65 |
| 359 | Headrest | 70 00 | 56 25 | 1 25 | | $126 25 | $126 25 |

**Fig. 3** Purchase Order form for RTS client with prior approval

| UB code# | Description of item | Size | Quantity | Price/each | Man code # | Manufacturer |
|---|---|---|---|---|---|---|
| 187 | Memphis Back kit | adult | | 220 00 | Memk-ad | UTREP |
| 1167 | Thoracic bracket | large 11" | 2 | 7 00 | Thor-lar | UTREP |
| 317 | Thoracic pad | large | 2 | 14 00 | Thor-pal | UTREP |
| 437 | Bead In Box Seat | 20w x19L | | 350.00 | | UB RTS |
| 1425 | Black Vinyl | 30" x 36" | | | CL06 | Pin Dot Products |
| 233 | Seatbelt | 1-1/2" wide. | | | SB1 | Pyramid Rehabilitation |
| 438 | Roho Insert | 6x10 | | 190 00 | special 6x10 | Roho Inc |
| 1958 | Head/Neck Support Fixure | single axis | | 42 61 | 430F2 | Otto Block Orthopedic |
| 359 | Headrest | 3 | | 50 00 | 430H1=3 | Otto Block Orthopedic |
| | | | | | | |

# COMMUNICATIONS AND CONTROL ELECTRONICS FOR THE DISABLED

Charles S. Eubank, Haniph A. Latchman
Department of Electrical Engineering
University of Florida
Gainesville, FL

## ABSTRACT

An overview is presented of the many communications and control products available to the disabled. This area has seen rapid growth since the introduction of the integrated-circuit and the microprocessor, offering the handicapped user a level of independence thought unreachable only twenty years ago. A brief comparison is made of today's products with those offered prior to the introduction of the microprocessor. Such a comparison clearly shows how advances in electronics have stimulated the design of many new and exciting products. Some of the most recent and innovative product developments are discussed.

## INTRODUCTION

A vast number of products have been created to assist the disabled, and the needs for these have never been greater. The number of handicapped individuals in the United States alone totals over 32.5 million people, accounting for 14% of the US population. The most prevalent disabilities are orthopedic impairments, arthritis, and heart disease, each accounting for over 11% of all handicaps. Visual impairments, intervertebral disk disorders, nervous disorders (including epilepsy and Parkinson's disease), as well as mental and hearing disorders each account for less than 5% of all disabilities. The total number of disabled persons has increased markedly over the past several decades, as has the number of assistive products since the introduction of the electronic integrated-circuit and the microprocessor. Volumes of catalogs have been published listing most commercially available items, and it would be impossible here to discuss more than an overview of the subject. However, many products are of similar function, and the intent of this paper is to present selected useful and innovative designs. Because the majority of these have been created for a specific handicap, it will be convenient to group and discuss related products under the disability they serve.

## A LOOK BACK

Prior to the introduction of the microprocessor in 1971, most electronic devices for the handicapped were actually more electrical by design, usually consisting of several switches and electromechanical actuators to provide control over such things as electrical appliances, wheelchairs, room lights, and telephones. Early systems mainly focused on the needs of the mobility impaired, not only because the electrical devices were so well suited for their needs, but also because it was the Veteran's Administration which was able to organize the support required for the development of such products. War casualties resulted in large numbers of disabled persons, many of these being paraplegic or quadriplegic, as well as handicaps due to loss of limb. The survival rate from such casualties was growing due to advances in the medical field following World War II, and thus the need for assistive technology became critical. The Veteran's Administration had the responsibility to fund such developments, from which emerged the automatic telephone dialer, the powered wheelchair and stair-climber, as well as an array of environmental controls. Unfortunately, development costs were high, and most of the products were extremely expensive. Competition in the private sector was slow to develop due to the relatively small market and prohibitive costs, and this caused assistive products to be limited in both number and scope. Even with the availability of the transistor in the 1950s and of integrated-circuits in the 1960s, major advances were not made until the mid-seventies, after the introduction of the microprocessor. The microprocessor reduced the size and cost of the computer so that businesses and hobbyists alike could develop practical and affordable assistive products. Since that time, major product advances have been made, resulting in a wide array of available programs and devices.

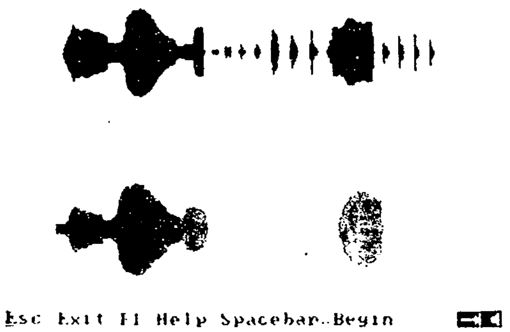
## OVERVIEW OF EXISTING TECHNOLOGY

### Products for the visually impaired

A variety of electronic devices are available for the blind and visually impaired. With the development of the image scanner, printed material such as documents or pictures can be converted into digital information and stored in computer memory. Conversion of this information into braille (for text) or a graphical-relief format (for pictures) can be implemented through an appropriate output interface. Alternatively, text can be converted to simulated speech using an attached voice synthesizer. This provides full access to all the text-based computer resources such as word processing, data bases, books, and software programming. For people with partial vision, screen magnifiers are available to allow programmable enlargement of video output Unfortunately, limited display area usually requires a lot of panning to access the complete image.

### Products for the hearing impaired

Compact hearing aids have been available for a long time. Solid-state electronic components have provided the means for an often inconspicuous amplifier to assist those hard of hearing. Recent advances now allow electrodes to be inserted in the inner ear which can stimulate the nerve fibers and produce a sensation of sound. Equipped with a small microphone and transmitter worn behind the ear, sounds are amplified, filtered, and digitized by an external processing unit before being passed through a magnetic coupling to the electrodes. Surgical installation of the device involves the placement of a disk-shaped receiver under the skin behind the ear, and the insertion of a thin tube in the ear's cochlea. The tube is banded with several contact electrodes to excite the auditory nerves. The external processor is tuned for each individual to provide an acceptable response to audio input. However, the resulting sound sensation is quite unlike normal hearing. Pitch detection is possible, but voice recognition is often quite difficult. At present, the aid is intended to assist with lip reading and provide an audio link for those individuals who can't benefit simply by sound amplification.




**A display showing output from IBM's SpeechViewer, comparing the speech patterns of a student and teacher.**

<u>Products for cognitive training</u>

Several software aids are available to assist with cognitive training. Such training is used to develop decision making skills for people with learning disabilities, or for those who have suffered severe head injuries resulting in partial or complete loss of identity or cognition. A useful technique is to present the student with games of choice, where the computer is used to pose questions and await an answer. Sophisticated programs might use a voice synthesizer to allow the computer to talk to the student. Several skill levels can easily be programmed to challenge an advancing student, and 'distractors' can be added to test the student's ability to make choices under adverse conditions, thus developing concentration skills. The computer also is able to record the progress of each session, allowing an administrator to monitor results over an extended period.

<u>Products for the speech impaired</u>

Several portable speech synthesizers are available to allow typed or selected phrases to be sounded upon command. Several designs permit the user to construct and store complete sentences, greatly improving response time for common situations. Some synthesizers even allow selections of both male and female voice types. Another innovative product is the speech training program, which utilizes the power of digital signal processing to provide the user with a visual indication of pronunciation. The human voice is composed of a complex mixture of many audible frequencies; using a microphone to enter the audio signal into the computer, the digital signal processor is able to separate the voice's complex structure into individual frequency components. This information can be compared against a stored reference pattern (the same word spoken without impairment) and the results plotted graphically to indicate how accurately the word was pronounced. In a simpler fashion, the voice can be digitally recorded by the computer and displayed graphically to show amplitude variations of the signal, as illustrated in the accompanying picture. Here, a speech impaired user can try to match the amplitude variations with that of a teacher sharing the microphone. Such feedback can easily be used in a game format so the learning process is enjoyable and captivating. The success of a word match (or close approximation) scores points for the user, or is used in some other positive way so as to motivate game play challenging for both children and adults.

<u>Products for the mobility impaired</u>

A process which has involved much research over the past several years is called Functional Electrical Stimulation (FES). This technique allows muscles isolated by paralysis to be driven into motion by external electrical signals that are coupled to the muscles through electrodes. A microprocessor-based controller issues the complex sequence of signals necessary to effect proper coordination of a muscle group. Commonly, this is used to produce a walking motion of the legs. FES does not yet allow unsupported walking, but the person is no longer confined to a wheelchair. By selectively operating the controller, the user is able to initiate each leg movement, one step at a time. Many other products for the mobility impaired involve computer access, discussed next.

<u>Products for computer access</u>

The desktop computer is useful only if one is able to access it using suitable input and output devices. Several alternative output devices have been mentioned earlier. For those people unable to move or accurately position arms and fingers, a special input interface is required to replace the standard keyboard. Such an interface has taken several forms and will depend on the nature of the disability. In an attempt to provide access for all forms of mobility impairment, the possibility of using *brain-wave activity* as an input trigger has been explored. To date, no reliable brain-wave interface has been developed due to problems of signal identification and high electrical noise levels. Electrical signals from *muscles around the eyes* have been used to determine optical focal points, but no commercial product is yet available employing this technique as an interface.

Other methods are being tried commercially, and these generally use some type of *reflection off the cornea* to determine the focal point on a video display. Using this information, a cursor can be positioned on the display with an accuracy of about 1/4 inch, and computer commands can be entered either by menu selection or by choosing letters from an alphanumeric display represented as a small keyboard on the screen. If the user is able to make *head movements*, a simpler method of cursor control can be implemented by using a head-mounted reflector and a stationary infrared transmitter/receiver. Head position is calculated using the reflected infrared beam, and this information is used to place the cursor. For cases where reliable head movements are impractical or impossible, an inexpensive alternative is to use a simple *switch interface* with a scanning cursor to select desired menu items. As the cursor scans through the list of choices, the switch can be activated to select the desired entry. A wide variety of switches for detecting body movements are available, including those for the tongue, lip, and eyelid. Touch-sensitive switches are available which require minimal pressure to trigger, and large contact areas can be used to allow easy activation by an arm, foot, or hand. Sip and puff switches can also be used. A new variation of switch uses a video camera attached to a computer to monitor the position of some part of the body, activating the switch only if that part of the body is placed in a specific portion of the computer's video image for a prescribed period of time. Such a switch requires no contact and the user is free of attached wires or devices.

A sophisticated form of computer input control is available using voice recognition software. Here, commands or textual information are sent to the computer simply by speaking in a microphone. Many such programs can recognize several thousand words for each reference file created by the user, making them quite suitable for word-processing applications and other text entry programs. The process works using advanced signal processing techniques to digitally record and analyze the frequency spectrum of each word spoken. This spectrum is compared to a word reference file stored in computer memory, where each word is represented by the user's unique spectral pattern. If a match is found, the word is written to the computer display. Should an incorrect match occur, the program allows the stored patterns to be modified and matched to the correct word. Sophisticated programs will modify spectral models of each match accepted by the user, in this way adapting the model to the user's voice. This is invaluable for people with mild voice impairments.

## NEW IDEAS

Johns Hopkins University has recently conducted a national search for computing applications to assist persons with disabilities, a competition designed to stimulate product development. Many of the entries were prototype models of what soon will be available commercially. Others are still unfinished designs, requiring several years of development before completion. An example is a proposed navigational aid for the blind, which will use an existing satellite network (the Global Positioning System) to determine the user's lateral and longitudinal position, from which commercially available mapping software can be used to pinpoint the location to a street name. With this information, the user can enter a desired destination and the software will calculate which streets to follow to reach that location. Contained in a shoulder bag and equipped with speech capability, the device is expected to be accurate to a radius of 20 meters.

A telephone communicator for the deaf was another entry in the competition. Soon to be available, this device is a portable, battery-powered unit which allows a deaf person to read coded messages that are sent to the device from a telephone's 10-digit push button keypad. The code is a simple, logical two-stroke process for each letter or number, and the messages appear on a small liquid crystal display. The connection to the phone is through a suction-cup attachment, using magnetic induction coupling with the earpiece. If the deaf user can speak, only one device is needed to provide two-way communication; otherwise, both parties will need the interface to decode the telephone's keypad signals. Already on the market from another manufacturer is a non-portable version of this communicator, using a desktop computer to provide sophisticated options and decoding schemes, as well as a speech synthesizer.

New ideas are continually developing as advances in electronics technology provide more powerful tools and methods. Future assistive products will undoubtedly benefit from the rapidly progressing field of digital signal processing. Also, as the size of electronic components continues to reduce, portability of complete and powerful computer systems will become practical, with the potential of transforming a wheelchair into a veritable workstation.

## ACKNOWLEDGEMENTS

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Charles S. Eubank
Department of Electrical Engineering
403 CSE, Building 42
University of Florida
Gainesville, FL 32611-2024

P2.13

# Service Delivery Via Slow-Scan Television

Charles J. Laenger and John Riddle
Kaiser Rehabilitation Center
Tulsa, Oklahoma

Abstract

A pilot program to determine feasibility of using slow-scan television to make initial assessments in the homes of rural, severely disabled clients is in progress. Three Interand Imagephones have been acquired with private foundation funds. One unit has been stationed in the rehabilitation center. Two units will be rotated between vocational rehabilitation counselors, case managers, care providers and social workers who have direct interaction with remote clients. The field user will be directed in setting up the equipment by a technician at the rehabilitation center. The field user will be directed by a therapist or other rehabilitation personnel stationed at the rehabilitation center. In this manner, the rehabilitation professional will determine whether a visit to the rehabilitation center for a hands-on, in-depth evaluation is justified. A budgetary estimate for equipment and technical services will be prepared for the third party payer.

## Background

Disabled clients who live in remote areas continue to be deprived of rehabilitation services. It is too expensive to send professional personnel into the field even to make assessments. Transportation and inconvenience of handling the severely disabled client enroute and away from home can be overwhelming. But reluctance to seek rehabilitation services is an even greater problem. Often clients or parents of physically and mentally retarded children are shy and do not believe that anything can be done to help. They have no idea of costs and often do not know that public financial help may be available. Often the visiting social worker, nurse or other field personnel tries in vain to convince these people to seek the aid of rehabilitation professionals. It is believed that slow scan television will provide great help, at low costs, in these situations.

## Statement of the Problem

Delivery of professional rehabilitation services to individual in sparsely populated areae is inordinately expensive. Field personnel who contact these clients and their families are not trained to make technical assessments nor to tell clients what methods and equipment are available. Often the rehabilitation center is many miles away making transportation and care of the severely disabled client a major impediment to acquisition of services. Training of field personnel and providing them technical information in a timely manner is a perennial problem. Funds for travel and training time are dramatically shrinking. Maintenance of equipment at remote locations is also a costly and inconvenient process.

## Approach

Slow-scan television is inexpensive, portable and very user friendly. Frames can be sent at a rate of two per minute over ordinary telephone lines. Even the most inexperienced person can be directed via telephone in set-up and use of this equipment. Initial assessments and education of the client, his family and the field worker can be accomplished with the aid of slow-scan television.

State vocational rehabilitation and developmentally disabled services agencies have agreed to participate in a pilot program. One unit will be consigned to each of these agencies.

Interand Slow-Scan Television System

State vocational rehabilitation and developmentally disabled services agencies have agreed to participate in a pilot program. One unit will be consigned to each of these agencies. Several trial run and in-service sessions will be held with the master slow-scan television station located in the rehabilitation center laboratories and the other stations located in various field offices.

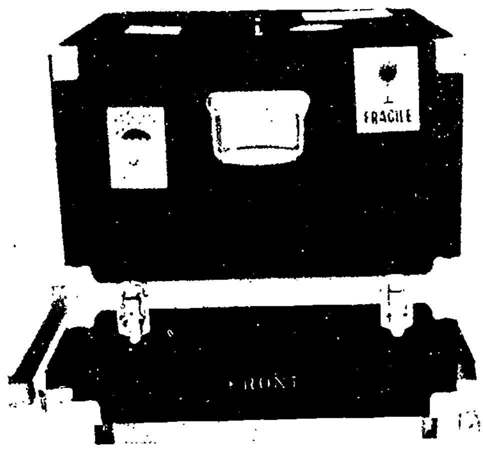
Clients will be encouraged to go to the field offices for evaluation where the vocational rehabilitation counselor, case manager, social worker, nurse or other contact personnel will operate the slow-scan television equipment, and take directions from the rehabilitation center professional staff. The field personnel will thus assist the professional rehabilitation staff to measure and specify wheelchairs, identify appropriate ADL equipment, identify trial environmental control and communication equipment, and make preliminary seating assessments. In many instances, the professional rehabilitation staff will get enough information to determine whether an in-depth seating or communication evaluation is warranted. In other instances, information thus obtained will help prepare the rehabilitation team for the in-depth evaluation. It will be possible to ship one of the units to the home where a person totally unfamiliar with the slow-scan television system will set it up and use it as directed. In this instance, the naive user will be instructed via telephone by rehabilitation center personnel.

The slow-scan television system will also be used to serve independent living centers and other special facilities as a technical information resource. Existing grant funds will permit such service on a limited basis during the first year.

Implications

It is believed that the slow-scan television system will enable technical rehabilitation specialist to serve rural clients better and at lower costs. This approach will also serve rural hospitals, professional field personnel, independent living centers and others. It will serve as a marketing tool for the rehabilitation center. It may also prove to be useful for rehabilitation technology and equipment vendors.

Slow-scan television, it is believed, will greatly benefit education and improvement of the technical capabilities of vocational rehabilitation counselors, case managers, independent living personnel and others. It should save money for state agencies, other third party payers and individuals.




Discussion

Slow-scan television is currently used to monitor drilling rig operation and other industrial processes. It is also used in conference applications and results in substantial savings in time and money. This approach should prove time and cost effective and serve as a valuable marketing tool for the rehabilitation community.

Acknowledgements

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Charles J. Laenger
Manager, Rehabilitation Engineering and Orthotics
Kaiser Rehabilitation Center
1125 South Trenton
Tulsa, Oklahoma 74120
Telephone (918) 584-1351 x7347

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# Accommodations for a Therapeutic Kayaking Program

Andrew Lincoln,RE, Richard Keller,RE, Lisa Lavery,PT, Lisa Pezzini,PT, Diana Burkhalter,OTR/L
Rehabilitation Engineering, Physical Therapy, Occupational Therapy
National Rehabilitation Hospital
Washington, DC USA

## Abstract

A kayaking program was recently developed for therapeutic purposes with the spinal cord injured population. To help insure the safety of the patients and increase the flexibility of the program, accommodations were made to the flotation system, the seating system, and mitts to allow for use of a paddle. These accommodations contribute to the success of an innovative treatment technique.

## Background

A Therapeutic Kayaking Program was developed by therapists at a comprehensive rehabilitation hospital. The purpose of the program is to facilitate improvements in sitting balance and upper extremity strength for increased independence in daily living skills. The program was piloted with patients with spinal cord injuries but will be expanded to include other diagnoses.

The equipment required for a kayaking program includes a kayak, paddle, seating system, flotation vest, and helmet. A sea kayak was chosen for the program for the following reasons: its flat bottom and short length provide increased stability; its larger cockpit size allows for ease of transfers and space for various seating systems; and its smooth interior of molded polyethylene offers protection to patients with sensory impairments. Two seating systems were utilized: the standard kayak seat with a gel pad or an adapted seat and back to provide additional trunk support. A standard jacket floatation device and helmet were used. The paddle that was selected was lightweight with an adjustable blade angle to accommodate the abilities of the patient.

## Objective

The three major concerns in making accommodations were kayak stability in the water, patient stability in the kayak, and paddle grip for persons with quadriplegia. To accommodate a patient population with sensory, balance, and mobility impairments, adaptations to the kayak, seating system, and grip of the paddle were required to meet patients' individual needs and enhance safety of the activity.

## Design

To maintain the kayak's stability in the water, outrigger floats were mounted to the kayak. The outriggers were constructed of a frame of telescoping aluminum tubing with fluid containers mounted to each end which act as floats. This frame was then mounted midline on the kayak behind the paddler after the patient transfered. It was fastened to the top surface of the kayak with a clamping system. The clamping system consisted of four machined PVC clamps mounted through the top of the plastic kayak into a 3/8" sheet of high density polyethylene. By sandwiching the top plastic surface of the kayak between the PVC clamps and the polyethylene sheet, slippage of the outrigger was eliminated and loading on the kayak hull was distributed. The telescoping feature of the outrigger frame allowed for the distance between the floats to be varied. By varying the distance between the floats or mounting the floats above or below the frame, the moment arm providing the buoyancy could be changed. Therapists could then control the degree of roll for individual patients.

To increase the trunk stability of higher level spinal cord injured patients, an adapted seating system was designed to substitute for the original low back seat. The adapted system utilized 3/8" ABS plastic to form a base. The seat and back were derived from the foam of a contoured cushion and minicell foam, respectively. A layer of silicon was added to the foam seat cushion to provide waterproofing. An abdominal binder was attached to the back with Velcro closures to maintain the position of the patient's trunk in the kayak. The back could be removed to give the patient additional space in the cockpit for transfers and then replaced and secured with thumbscrews.

Adapted kayak mitts were designed to hold the patient's hands in a functional grip position while allowing the paddle to rotate when the patient performed kayak strokes. (See Figure 1.) The design also provided the quadriplegic patient the ability to independently don and doff the mitts. The mitts were designed to be strong, durable, and comformable. Features of the mitts include a 1" strap of webbing secured around the wrist with Velcro; a 4" Velfoam pocket covered the back of the hand and fingers; and two 2" straps secured the hand to the paddle. The thumbs were free from the mitts in opposition.

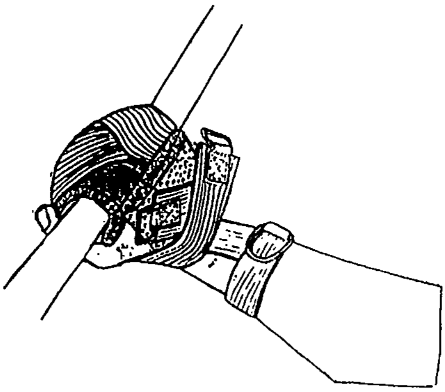

Figure 1 - Kayak mitt

Discussion

The accommodations made for the therapeutic kayaking program were an effort to insure the patients' safety. The outriggers prevented excessive tipping even for heavy patients. The adapted seat secured the position of the patient in the kayak. Materials selected for the seat and mitts provided cushioning for good pressure distribution for patients with sensory impairments. The kayak mitts can be doffed in case of emergency, and the helmet and life vest offer additional protection in case some unforeseen incident occurs.

The accommodations also offer a degree of flexibility for patients with varying levels of strength, balance, and dexterity. The adjustable outriggers allow for the controlled development of a patient's balance. Different seating systems can be installed in the kayak to provide adequate support for patients based on their specific level of injury and the back of the adapted seating system can be temporarily removed to facilitate transfers. The Velcro-fastened abdominal binder allows for varying degrees of trunk support based on the patient's build and trunk control. Also, the kayak mitts allow patients with adequate shoulder strength but limited hand function the opportunity to hold the paddle in order to assist in the development of strength and balance.

These accommodations were achieved through an interdisciplinary effort. It is through such efforts that quality of care can be enhanced to offer patients unique, effective, and enjoyable treatment techniques.

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Contact:
Andrew Lincoln, Sr. Rehabilitation Engineer
Assistive Technology / Rehabilitation Engineering
National Rehabilitation Hospital
102 Irving Street, N.W.
Washington, DC 20010

P2.15

# Retrofitting: A Case for Community Clinician Input

Aimee J. Luebben
University of Southern Indiana

## ABSTRACT

For a variety of reasons community clinicians are often not consulted in decisions to determine appropriate assistive technology for persons with disabilities. At times, however, therapists working in community based agencies must secure funds for retrofitting inadequate seating and wheeled mobility systems that are missing functional and safety adaptations needed for community utilization. In a retrospective study of 67 seating and mobility systems, it was determined that input from community clinicians prior to and/or during a seating and wheeled mobility evaluation decreased the likelihood of retrofitting inappropriate systems.

## BACKGROUND

With the need to broaden services to remain competitive, most hospital based therapy programs have a seating and wheeled mobility component. For the seating and mobility clinic, the rate of success (determined to be selection of the device appropriate to the client without the need for retrofitting the system within one month) varies depending on the background, education, experience, and continuing education of the team members. The rehablitation technology supplier (RTS) provides many of seating and mobility systems, particularly in rural areas of the country. The success rate of the dealer also varies for the same reasons as the team in the hospital.

Regardless of evaluation location or membership of the team members, many times community clinicians, who are often not consulted, must deal with retrofitting new seating and wheeled mobility systems that are sometimes inappropriate and other times missing functional and safety adaptations needed for utilization in the community (Luebben and Young, 1989). Community therapists are becoming increasingly more active in the evaluation, decision making, fitting, training, and followup of seating and wheeled mobility systems. Because of a recent court decision, the impetus to move away from referring clients to hospital based programs will likely escalate, particularly for those therapists who serve school districts. In Bertetto v. Sparta Community Unit District No. 140 (1989) the school district was determined to be potentially liable for injuries suffered by a student with disabilities who was thrown from her wheelchair while being transported to the playground. The lower court decision, ruling in favor of the school district by holding the district not liable since the student's parents furnished the wheelchair, was overturned by an appeals level decision that held the district liable with the premise that it was the school district's duty to furnish equipment to prevent serious injury.

Third party reimbursement sources, obligated to curb escalating health care costs, are cognizant of the increase in the requests for extra funds being sought to complete the retrofitting necessary for community utilization. In the future, funding for retrofitting by third party payers may be jeapardized or even halted if this trend to make equipment changes, modifications, or additions continues.

## RESEARCH QUESTION

The purpose of this study was to determine whether input of community clinicians influences the incidence of retrofitting seating and mobility systems. Investigated was the research question, "Do seating and wheeled mobility evaluations and fittings performed with the input from community therapists result in a higher rate of success (lower incidence of retrofitting) than those evaluations performed without community therapist involvement?"

## METHOD

The subjects for this study were students receiving new wheelchairs beween December 1987 and June 1991 in agencies served through contracts with a community based private practice. Two variables, community clinician involvement and the need to retrofit the seating and mobility system within one month of delivery and final fitting, were included for investigation of the research question. The community therapist input variable was coded as "with" when the input from one or more comunity therapists was provided before and/or during the seating and wheeled mobility assessment and subsequent fitting, whereas "without" designated seating and wheeled mobility assessments that were completed without the input of the community therapist(s). The second variable, the need to retrofit a new wheelchair, further subdivided the students. The wheelchairs were divided into four groups: (a) with community therapist input, no need to retrofit; (b) with community therapist input, need to retrofit; (c) without community therapist input, no need to retrofit; and (d) without community therapist input, need to retrofit. A chi-square test for independence was conducted to determine whether the need to retrofit seating and wheeled mobility systems is independent of input from one or more community clinicians.

## RESULTS

Within the group categoried as without community therapist input and needing to retrofit, whether a therapist working in a facility not based in the community was involved the assistive technology decision making team was not differentiated from a team that involved the RTS without any therapist. Since equal numbers (10 each of the 20 decisions made without community therapist involvement) of noncommunity based therapists and RTSs (without therapy credentials) required retrofitting, both types of personnel were classified into the same category.

Sixty-seven seating and wheeled mobility devices were delivered to students between December 1987 and June 1991. Of the total number of seating and mobility systems, 40 were classified as with community clinician involvement and 27 as without community therapist input; 26 categorized as requiring retrofitting and 41 as not needing to be retrofitted. Six of those 26 systems requiring retrofitting had the input from one or more community therapists while 20 units were delivered without community information. Of the 41 devices that did not need to be retrofitted, the decisions regarding 34 systems were made with the input of community therapist(s) and seven nonretrofitted systems did not information from the community.

An examination of the observed frequencies of the four groups demonstrates that the likelihood of retrofitting seating and wheeled mobility system significantly decreases with community clinician involvement in the decision making process, chi-square $(1, n = 67) = 23.686$, $p<.05$. According to Cohen (1988) the phi of .5945 calculated for this study shows a strong relationship between the two variables (community therapist input and need to retrofit). From power analysis tables, the power of this chi-square test (one degree of freedom, sample size of 60, alpha level of .05, and effect size of .50) is .97. For this study it appears evident that the higher rates of success in providing appropriate seating and wheeled mobility systems with community therapist input is not due to chance.

## DISCUSSION

Caution in generalizing the results of this study must be observed since this was a retrospective study conducted in one geographical area. However, retrofitting does not appear to be a localized event, but occurs across the country. To decrease the incidence of retrofitting, it seems that there are at least two solutions. With the seating and wheeled mobility evaluation occuring outside of the community based agency, the most simple solution is involving community therapists at the time of the evaluation. For the most part, the physical presence of community clinicians is impossible because of scheduling and funding; however, phone contact or an intake form would provide team members with information necessary to make informed decisions. The second solution for hospital based therapists is to spend some time in the community with their clients. Since life situations must be simulated in the noncommunity settings, oftentimes the hospital therapist is unmindful of needs that cause the most retrofitting. Two community related areas most commonly forgotten are safety, particularly during transportation to and from school, and stabilization for functional tasks.

## ACKNOWLEDGEMENTS

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Aimee J. Luebben, Director
Occupational Therapy Program
University of Southern Indiana
600 Edgar Street
Evansville, IN 47710-1624
812-428-7202

# Challenges in Long Distance Prescription

Lynne Balfour OT(C), Jerzy Antczak P.Eng.
Rehabilitation Engineering Department
Hugh MacMillan Rehabilitation Centre
Toronto, Ontario, Canada

## INTRODUCTION

In August 1990, Hugh MacMillan Rehabilitation Centre's Rehabilitation Engineering Department was contacted by a Rehabilitation Centre (over 2000 miles away) in Western Canada to investigate whether we could make suggestions for and/or supply specialized seating and powered wheelchair controls for one of their clients.

The client was a 25-year-old college graduate with spinal muscular atrophy who was losing strength and the ability to use a joystick. She wanted to be as independent as possible and work at least part time in her profession. The client was very articulate, a good advocate for both herself and others. She communicated with us by letters written, we discovered later, using a sip and puff switch and Morse Code on a computer.

As it was difficult to make suggestions without seeing the client's quality and quantity of movement we requested that a videotape be sent to us showing her seating system, her driving method and discussing her needs. This was made by her physical therapist and occupational therapist. It gave us basis for delineating the problems and possible solutions. A second videotape made a few months later of her specific hand movements helped us narrow down choices in wheelchair controls.

## OBJECTIVES

The requests were:

1. A new powered wheelchair with a tilting mechanism, not to exceed 25" in width or a seat height of 21". Wheelchair had to be an E&J product as that was only one supported by the provincial funding agency. Width was critical because of home doorways and the family van lift.

2. A seating system to give full body support, accomodate a moderate scoliosis, give a variety of positions for head support, and full arm support. Her strength changed during the day necessitating a variety of head positions. Back and shoulder pain was a problem.

3. The seating system had to fit both the new powered wheelchair and a presently owned manual wheelchair.

4. The seating system should allow our client to be lifted in it and fit on the seat of an airplane (17"), (her hips measured 18"!). Excessive hip flexion in lifting caused her severe back pain, sometimes resulting in many days in bed. She did not like to be lifted except by very familiar people. She also wanted to travel.

5. A wheelchair control that would be easy to use, and change with her fluctuating strength during the day. While she presently used a joystick, by noon she had often lost strength and could not move her arm to control it.

6. Any fittings or work would have to be done in one short stay. She was overage for our hospital, but fortunately could stay in our family motel with her parents.

## FITTING PROCEDURE

### Seating

We embarked on a year of correspondence between our team and the client and her team, using videotape, letters, phone and fax. As we narrowed down choices, the home team ordered the wheelchair and had it delivered to a manufacturer of wheelchair tilters. The manufacturer modified the tilt mechanism to the client's height and width specifications, and delivered it to our Centre. Our client and her family flew in to stay for two weeks.

We discovered that even a videotape did not tell the whole story. Even a 1" change in seating position changed her ability to hold her head in position or move her arm. She could not move her arm at all against gravity. She could wiggle her left thumb and all her right fingers but not grasp anything. She controlled the joystick primarily with shoulder movement. Occasionally she would resort to driving backwards because the movement was easier.

We made a poured foam back with a very wide elasticated body support giving total abdominal control. The seat was a sandwich of multiple layers of plastizote and high density foam to keep it as thin as possible. One of our technicians developed a three way adjustable bracket for the headrest. The seat-back angle was critical and fixed with a metal bracket. Lifting straps were attached to the back and sides of the seating system. The system sat on plywood bases in each wheelchair that had plastic clamps and guides to hold it.

**Wheelchair Control**

The final challenge was interfacing of the wheelchair control. She had less movement than we had thought, and we were afraid that she might lose that in the near future. In order to allow her to accomodate her way of driving in accordance with her fluctuating strength, it was decided to use the Invacare 1551ME controller on the E&J wheelchair. She wanted to use the proportional joystick whenever possible as it gave the most precise control. A curved lexan surface was attached to the inside of the right side mounted joystick box. This contained three very small touchplate switches (fwd./right/left) with another on the curved upper surface (mode change). Instead of these touchplates being direct selection of direction, we fed them through a Micro-Scanner Interface box, which allows one switch to control forward and reverse directions, and provides a way to change controls in the future if her abilities change and only one movement is available to access switches.

She now can drive using three methods, the proportional joystick in the traditional manner, the proportional joystick as a RIM control (forward accessed by pulling back), or by using her thumb to access the four touchplates (digital input). Any of these controls will activate the tilt mechanism (by moving out of wheelchair mode into the ECU mode). There is also the potential to use these same controls for accessing other environmental controls through ECUs available on the 1551ME controller.

**CONCLUSIONS**

It was necessary to have our client find a local person experienced in electronics who could make the ongoing adjustments that will be needed by someone with a changing medical condition. There are also changes required on a regular basis in the exact positioning of her arms and for seat comfort.

Working with a client and team from such a distance presented many challenges, which through intense communication combined with a stay at our Centre, resulted in a satisfactory outcome. However, as with any client with a changing medical condition, it will fall to the home caregivers to continue to maintain and modify the system and make it both comfortable and useful for our client.
At present our client enjoys using the system effectively, switching among control options as needed.

Jerzy M. Antczak
Rehabilitation Engineering Department,
Hugh MacMillan Rehabilitation Centre,
350 Rumsey Road,
Toronto, Ontario, CANADA, M4G 1R8

P2.17

# DEVELOPMENT AND EVALUATION OF WHEELCHAIR CUSHION PROTOTYPES

Stephen H. Sprigle, Laura Cron
University of Virginia
U.S.A.

## INTRODUCTION

The use of foam cushions by wheelchair users has been studied for several years by many researchers. The general conclusion of these studies was that wheelchair users must be evaluated individually for a cushion and that no single cu.`ion is appropriate for all users (Garber). Foam offers several beneficial characteristics when used as a support surface, including good envelopment, good impact damping, and a stable sitting surface (Ferguson-Pell). Other attractive features are it's low cost and ability to be fabricated with many different material properties and in different shapes and sizes. Currently, over 100 foam cushions are available commercially and range in cost from around $20 to over $200.

## OBJECTIVE

The goal of this project was to develop inexpensive foam wheelchair cushions which are effective in preserving the functional abilities of the user while not increasing the risk of pressure ulcers. The evaluation was simply meant to judge the performance of the cushion prototypes and was not meant to compare these cushions to any other commercial cushion.

## METHODS

Prototype wheelchair cushions were designed to address different needs of wheelchair users. A cushion with a unilateral thigh cutout was designed for use by individuals that use one leg to assist with wheelchair propulsion. A segmented wheelchair cushion was designed to provide adequate pressure distribution, and was targeted to the general wheelchair population. After prototype testing and redesign, two cushion designs were produced and evaluated by pressure measurements and extended clinical trials.

Pressure Evaluation. Volunteer subjects were seated on a prototype cushion secured to a manual wheelchair. Seat interface pressures were measured within a 5" by 9" rectangle using an Oxford pressure monitor (model TM700 or MKII). The transducer was centrally placed under the ischial tuberosities. Pressures were measured at each of the 24 locations.

Clinical Evaluation. Volunteers were positioned on a prototype cushion by their primary Occupational Therapist. Proper adjustments were made to the wheelchair to accommodate the new cushion. The cushion was encased in a nylon and spandex cover which was secured to the wheelchair. Clinical evaluation forms were provided to each therapist to complete after each clinical trial. The *segmented cushion* form required the evaluator to rate the performance of the cushion in 7 ways. The subject's skin reaction, posture, effect on transfers, change in spasticity, effect on propulsion, comfort, and balance were assigned a value between 1 and 5. The *hemi cushion* evaluation form required the therapist to judge sitting balance/posture and propulsion ability on a 0 to 5 grading scale.

### *Unilateral Cutout (Hemi cushion)*

Description. The hemi cushion was designed for persons who use one leg to assist with wheelchair propulsion. A section of the foam was cut-out which resulted in one side tapering from the original 3" thickness to a 1" thickness at the front (Figure 1). The cushion was fabricated from HR45 foam.

Results: Interface Pressure. The results of the pressure measurements of 11 subjects are shown in Table 1. Mean pressures, and peak pressure values of the cut-out side (propulsion leg) and support side (affected limb) are listed.

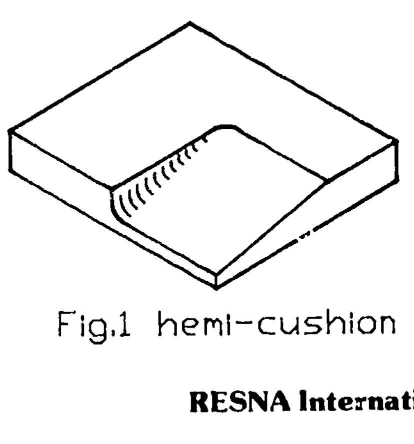

Fig.1 hemi-cushion

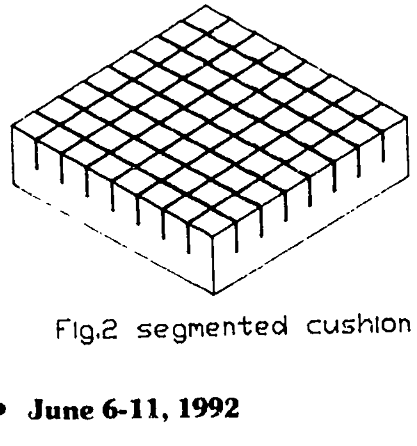

Fig.2 segmented cushion

The cut-out (propulsion) side had higher peak pressures in 2 of the 11 cases. A bilateral peak pressure difference of >10 mm Hg was found in 5 subjects. In 4 of these cases, the support (affected) limb experienced the higher pressure.

Results: Clinical Evaluation. Eleven subjects participated in the clinical trails which varied in length from 4 to 7 days.

The therapists judged that 6 of the 11 subjects could achieve normal or near normal posture and balance; and 3 could approximate a normal posture.

Nine of 11 could propel a wheelchair independently with a fair to good sitting posture. Three of these improved propulsion ability on this test cushion when compared to their regular cushion.

None of the subjects exhibited any skin redness during the evaluation period.

Discussion. Pressure measurements were used to judge the cushions ability to distribute pressure effectively and to determine if the unilateral cutout induced a pelvic obliquity. The results indicate that despite the difference in leg support and the difference in the angle of the hips, no significant variations occurred. This tends to support the notion that the cushion did not induce an asymmetrical posture in the subjects tested. A pelvic obliquity would have been indicated by a difference in the right and left side pressure measurements.

In the few instances where a pressure difference of over 10 mm Hg was recorded, the higher pressure was found on the *support* (affected) limb. This might have resulted from a decrease in loading under the thigh, caused by the height of the footrest on the *support side*.

The results were quite encouraging. The pressures measured at the buttock-cushion interface were generally acceptable, and none of the subjects exhibited a pelvic obliquity as a result of the cushion design.

Table 1. *Interface Pressures- Hemi Cushion*

| | | | Peak Pressures | |
|---|---|---|---|---|
| Sex | Diag | Mean Press | Cut-out Side | Support Side |
| M | R-CVA | 35.1 | 46 | 50 |
| M | R-CVA | 55.2 | 98 | 98 |
| M | L-CVA | 71.0 | 105 | 101 |
| F | L-CVA | 41.3 | 44 | 79 |
| M | R-CVA | 58.2 | 71 | 88 |
| M | L-CVA | 46.9 | 93 | 63 |
| F | L-CVA | 35.7 | 55 | 58 |
| F | R-CVA | 40.0 | 57 | 66 |
| F | R-CVA | 43.7 | 50 | 97 |
| F | R-CVA | 38.1 | 47 | 54 |
| F | L-CVA | 31.8 | 46 | 62 |

Clinical evaluation results were varied, yet encouraging. Ten of the 11 subjects chose to continue using the hemi cushion after conclusion of the study. Subjectively, they reported easier management of the wheelchair with less energy exertion and increased comfort.

This may signal a specialized use for this type of cushion. The cushion was designed to provide wheelchair users with better access to the ground for propulsion purposes, while providing adequate cushioning under the buttocks.

The seat height of a wheelchair is usually 19 inches from the floor. The addition of a wheelchair cushion will increase this seat height another 1-2 inches. This height makes it difficult for a person to reach the ground. Hemi height wheelchairs with a lower seat height are marketed but may not be available to many people, especially those people who use loaner wheelchairs during their recovery in the hospital or rehabilitation facility.

If a person cannot reach the ground to propel adequately, they often slide their buttocks forward in the seat, allowing their hip to extend enough to reach the ground. This maneuver often results in a sloughed kyphotic posture which is generally unacceptable. The unilateral cutout cushion was designed to allow a person to extend their hip to reach the ground without having to slide forward on the seat. As the results indicate, this was often the case, but some subjects could still not maintain an erect posture.

In conclusion, this unilateral cutout cushion does seem to have characteristics which may aid certain wheelchair users. However, its efficacy must be determined on a case by case basis.

*HR2855 Segmented cushion*

Description. A 3" cushion, fabricated from HR2855 foam, was divided into 2" by 2" segments with 1 1/2" depth (Figure 2).

Results: Interface Pressure. The results of the pressure measurements on the segmented HR2855 cushions are shown in Table 2. The peak pressure range reflects the highest recorded values on the right and left sides. Each cushion showed substantial variation from subject to subject.

Table 2. *Pressure Evaluation - Segmented Cushion*

| | | Pressure (mm Hg) | | |
|---|---|---|---|---|
| Sex | Diagnosis | Mean | St. Dev. | Peak |
| F | mult trauma | 45.7 | 17.5 | 79-85 |
| F | head injury | 46.2 | 16.0 | 68-83 |
| M | Guil. Barre | 47.3 | 22 5 | 73-126 |
| M | mult trauma | 45.8 | 15.7 | 70-76 |
| M | sci-incompl | 63.5 | 32.0 | 127-131 |
| M | sci-incompl | 49.5 | 15.7 | 59-80 |
| F | sci-compl | 37.5 | 9.7 | 43-56 |

The segmented foam cushions seemed to provide poor support in two instances. The inability to provide proper support in these cases may have been because the foam bottomed-out under the patient's load.

In most cases, the pressures were quite adequate with mean pressures in the 40 to 60 mm Hg range and peak pressures in the 60 to 80 mm Hg range.

Results: Clinical Evaluation. Twelve forms were returned during the evaluation period. Clinical trials ranged from 4 days to over 2 months. Subjects exhibited a variety of physical disabilities including 3 CVA, 1 head injury, 4 SCI and 4 persons with other physical disabilities.

The subject's skin was clear in 10 cases. Two subjects exhibited slight coloration but neither subject was removed from the cushion due to prolonged redness.

Posture was reported as *good* in 9 subjects. The therapists reported posture as *fair* in 3 cases.

Spasticity remained unaffected in all subjects.

All subjects reported a *fair* to *good* level of comfort while seated on the cushion.

Transfers were unaffected in 10 subjects, but were slightly hindered in 2 cases.

The ability to propel a wheelchair was unaffected in 11 cases. Propulsion seemed improved for one subject.

The cushion had no effect on the balance of 8 subjects. Three subjects experienced improved balance, and balance was compromised in one case.

Discussion. The clinical evaluation of the segmented cushions produced very good results. The many different types of people who clinically used this cushion seems to infer a beneficial versatility of its design. The cushion did not seem to have a consistent detrimental influence on any of the clinical variables. As with most cushions, it seemed to work better with some people than others, but overall, the cushion performed quite well.

Four clinical variables; skin coloration, posture, effect on spasticity, and comfort received judgements of *adequate* to *good* for all 12 subjects.

The other three variables; effect on transfers, effect on propulsion, and balance received favorable ratings in over 80% of the cases.

Discussions with some participating therapists revealed their overall satisfaction. They felt that this cushion provided a nice stable sitting surface that was generally comfortable to their patients. They also liked the versatility of the cushion and the ability to modify the cushion easily to provide additional pressure relief in certain areas.

Often the therapists felt that a patient would benefit from a cut-out on the cushion surface. The segmented cushion lends itself well to this sort of modification. By using scissors or an electric knife, a therapist could easily remove a few segments. The resulting depression in the cushion's surface offers reduced loading on that area of the buttock or thigh.

## CONCLUSIONS

The goal of this project was to develop versatile, inexpensive cushions that could be used with patients in an acute hospital or rehabilitation facility, or could be used as an everyday cushion by wheelchair users upon discharge. These cushions were designed to offer an alterative to the other foam cushions currently available, but was not meant to be a replacement to some of the high-cost, adjustable or customized cushions.

In addition to designing these cushions to provide a safe and functional seating surface, they were designed to be a cost-effective alternative to other commercially-available cushions. Span America (Greenville, SC) has begun manufacturing both the *Hemi Cushion* and the segmented cushion (marketed under the name *Geomatt PRT Cushion*). The suggested retail price of the *Hemi* cushion is $19.25 and the *Geomatt PRT* is $22.50. Covers must be purchased separately. Based on the pressure and clinical evaluations, these cushions should be considered as cost-effective options when evaluating client's for wheelchair seating.

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For further information, please contact:

Stephen Sprigle
University of Virginia
Transportation REC
P.O. Box 1885 - University Station
Charlottesville, VA, USA 22903
(804) 296-4216

P2.18

# CUSTOM MOLDED SUPINE, SIDE LYING, AND PRONE POSITIONERS

Kurt Harmala, Matt Gonzalez, Valerie Musselman, Donna Crawford, Steve Cielinski
Rehabilitation Technology Services/Rehabilitation Engineering Program
Department of Physical Medicine and Rehabilitation
University of Michigan

## ABSTRACT

For severely involved clients with limited sitting tolerance, alternative positioning is a concern. Because of musculoskeletal limitations and/or spasticity, conventional alternative positioning devices are frequently inadequate in achieving and maintaining the desired alignment. Custom molded positioners in supine, prone, or side lying provide an alternative.

## BACKGROUND/PROBLEM STATEMENT

For individuals with severe musculoskeletal deformities as a result of cerebral palsy, brain injury or other conditions, positioning is necessary to retain existing structural alignment and joint mobility. For those who cannot sit for long periods of time, successful positioning can be a challenge. Prone, supine, and/or side-lying positions provide other options to sitting. Common methods of positioning people in the supine, side lying, and prone position include pads, bean bags, and planar systems with modular components. Another option is a custom molded foam positioner which is fabricated using foam-in-place technology(1). This type of positioning system can be stationary or mounted on a mobile base. This paper focuses on assessment for and fabrication of custom molded horizontal positioning systems.

## ASSESSMENT:

The client is usually referred as a result of a recognized need to position the client in an alternate position to sitting. An evaluation is done with an occupational and/or physical therapist, technical seating specialist, parents and other care providers. A custom molded alternative positioner is considered only when commercially available items cannot adequately support the patient because of the degree of deformity and/or abnormal muscle tone. The desired position is determined based upon the following factors: primitive reflex influences, the effect of position on distribution of muscle tone, postural alignment, and range of motion. Below is a brief overview of some the indicators for each position.

A molded supine positioner is chosen when the client frequently lies in the supine position, but asymmetrical extensor tone undesirably influences the position when they are not supported well. Frequently there is an unstable hip joint. These clients can not usually tolerate being positioned in the prone position.

A molded side lying positioner is chosen when the client has severe kyphoscoliosis of the spine and associated deformities of the pelvis and lower extremities. In this case, prone and supine positioning are not tolerated because of the deformities and a commercial sidelyer may not be able to provide adequate support.

A molded prone positioner is chosen when there are severe hip flexor contractures and symmetrical support of the trunk is desired. It also allows for more upright orientation of the head and upper body to use available upper body extension.

Once the client's position has been established, the orientation of the positioning system must also be resolved. This decision is based on the effects of position in space upon the client and how the positioner is to be used. If the positioning device is to be mounted on a mobile base, the mounting specifications are also determined at this time.

## METHODS:

A molding frame(2), which incorporates vacuum consolidation techniques to hand form custom molded seats and backs, must first be modified to achieve a seat to back angle range of approximately 150° to 230°. The angle varies depending on whether the position is to be prone, supine, or side-lying. The patient is transferred onto the molding frame and manipulated until the desired position is achieved.

When molding a person in a supine or side-lying position, the seat-to-back angle varies between 150° and 180°. The seat on the molding frame is used to mold the pelvic area and lower extremities while the back section is used to mold the trunk and upper extremities (see figure 1).

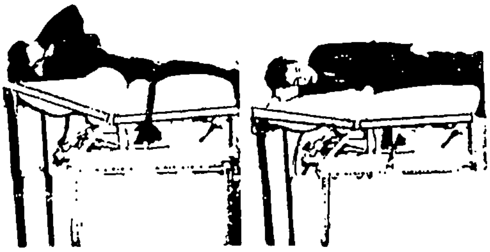

Figure 1: 150°-180° seat to back angle

To mold a prone positioner, an angle of 180° or greater is required of the molding frame. With our molding system, the seat section is placed in a horizontal position and the back portion is pivoted down for a seat to back angle of greater than 180°. In order to properly align the frame for prone positioning, the seat must be elevated to be flush with the back. The back section of the molding frame is used to shape the lower body, while the seat section is used to support the trunk horizontally. (see figure 2).

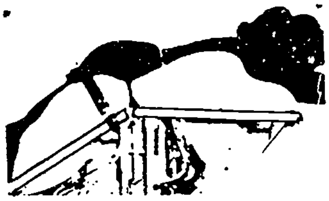

**Figure 2: 180°+ seat to back angle**

The molding frame is used to form a positive mold which is cast with plaster splinting material to produce a negative mold. It is important to apply the splinting material over the sides of the mold down to the edges of the molding frame. This will create a flat and parallel surface on the bottom of the negative mold, which is essential for proper orientation of the finished positioner.

After the plaster cast has dried it is prepared for the pouring of the liquid foam-in-place. Preparation consists of smoothing the inside of the cast and coating it evenly with a non synthetic release agent such as paraffin wax.

Fabrication of the cushion involves pouring liquid foam-in-place into the prepared cast (the expansion of medium density foam-in-place is approximately thirteen times it's original liquid volume). Sheets of reinforced plastic are clamped against the open end of the cast to control the flow of the foam-in-place as it is setting. This forces the foam down so that trapped gases will not create a void. It also stops the foam from rising beyond the edges so that the correct orientation is achieved in the final product.

After the foam sets, it is removed from the cast and mounted to a firm base. This makes the positioner inflexible so that its shape will not be distorted. When making a side lying positioner, it is necessary to support the patient along the back as well as the side. In this case the base will consist of two planar surfaces, perpendicular to each other. The vertical surface of the base extends behind the patient so that a foam-in-place back can be formed from a bag. The contoured back allows some of the weight-bearing to be distributed to the patient's back as well as the side if they are to be tilted.

Positioning straps are attached to the base and modifications should be made if they are needed. Once the desired positioning is achieved, the cushion should be appropriately finished to make it durable, aesthetically pleasing, and waterproof when appropriate. This is accomplished at our facility by vinyl-coating the positioner(3).

## DISCUSSION

Positioning outside of a seating system is recognized by rehabilitation professionals as an important part of the therapy program for individuals who cannot sit for long periods of time. The time spent out of the chair is no longer viewed as rest, but an important part of the day. A custom molded alternative positioning device may be beneficial to a persons body structure, joint mobility, and organ functioning. It can also augment or supplant the use of extremity splints and orthoses by providing the desired support and alignment of body parts. The positioner can also be designed to support other therapeutic objectives such as visual attending, switch access, and positioning for feeding.

When a client has multiple care providers, an advantage of a custom positioner is that it ensures consistent optimal positioning with minimal placement of separate positioning elements. The training required for the care givers is brief and easily supported by photographs.

Therapists and family members of clients have reported that pain, muscle spasms, irregular respiration and digestion problems are often decreased with the use of a horizontal positioner. More empirical evidence is necessary to increase the understanding of the effects of positioning on bodily functions.

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## SUPPLIERS:

1. Dynamic Systems
   Route 2, Box 182B
   Leicester, N.C. 28748

2. Pin Dot Products
   6001 Gross Pointe Rd.
   Niles, IL 60648

3. Danmar Products
   221 Jackson Industrial Dr.
   Ann Arbor, MI 48103

Kurt Harmala; University of Michigan Rehabilitation Technology Services; 2850 S. Industrial Hwy, Suite 200, Ann Arbor, MI 48104
(313) 998-7873

P2.19

# A MULTIFUNCTIONAL NAPE JOYSTICK

Massimo Ferrario, Marco Lodola
Servizio Informazioni e Valutazione Ausili
Fondazione Don Carlo Gnocchi
Milano, Italy

## ABSTRACT

During an experimental project financed by the Region of Lombardy, Italy, we tried to identify some solution for the independence of severe quadriplegic persons.
Owing to the necessity we had to solve a lot of problems, both technical and psicological.
In this paper we would like to present a simple method for the construction of a multifunctional nape joystick.

## BACKGROUND

A short practical test at Marco's home (Marco is a quadriplegic C4-C5) gave us the chance to identify some problems related to the use of different models of chin joystick. He showed the frequent need to perform very pronounced trunk passive flections to limit the discomforts that are not felt, but perceived, due to the traumatic lesion of the cervical spine.
It looks like these discomfortable feelings are provoked also by keeping for a variable time span a practically erected position of the body. They occur with an intensive perspiration, a feeling of need of movement due to a sensation of stiffness of the spine, a light dizziness.
The presence in a front position, near the face, of the chin joystick, even if relatively small, hampers, without first proceeding to move it, Marco's trunk flection, and furthermore limits the possibilities to take ad-vantage of the residual flection and rotation head movements, needed to operate the keyboard of a personal computer and an amplified telephone, by means of a stick held in the mouth. Finally, Marco clearly and meaningfully stated his fee-ling of discomfort for the presence of a box interposed as a partition screen between himself and another person during a conversation.
From what above we understood that Marco's feeling was of something that hides, protects, avoids that one can expose himself by clearly showing one's face, almost as this chin joystick in front of his face limit by its own a chance of rela-tion at the same level, as if it were identified as an invalidating tool.
At the same time Marco referred a second discomfort related to his need to verbalize, greatly limited since he had to control all the little movements of his chin in order to avoid to perform undesired movements with the wheelchair.

## OBJECTIVES

These problems led us to look for electronic wheelchairs with a nape joystick control, to try to avoid the use of almost all the flection movements of the head, and take the greatest advantage of the extension, rotation and lateral flection possibilities.
We could identify a little number of wheelchairs complete with nape joystick, that, as for Marco's needs, showed some defects, particularly related to their overall dimensions.

## METHOD APPROACH

We therefore proceeded and requested to construct a custom-made electronic wheelchair and to realize a prototype of a joystick that can operate it by using limited nape movements.
Marco expressed the following needs:
1 a wheelchair allowing the autonomous control, even if of few degrees each time, of the bending angle of the back of the seat, in order to be able to vary by himself the sitting position.
- 2 allowing him to reach a position near to the horizontal to relax during some moments of the day without being compelled to move from the wheelchair to the bed
- 3 allowing him to reach in an autonomous manner the upright position, since it encourages many organic functions
- 4 he finally stated that most of the use of the wheelchair would be inside the house, admitting also the possibility of use outside
The construction of the custom-made wheelchair was requested to an italian firm, and allows, in its standard version, the simultaneous variation of the inclination of the back of the seat and of the footboards, until a semi-lying position, and, going back through the sitting position, the modification of the seat inclination, raising at the same time the back of the seat into a vertical position, to achieve the assisted upright position.
The movement can be stopped any time, and allows to run even few degrees each time.
A peculiarity we would underline is referred to the possibility to move, by means of the wheelchair joystick, regardless of the positions of the seat, the back and the

footboards, especially on smooth floors
When requesting the custom-made construction, we included the reduction of the overall width from 62 cm to approx. 51, more suitable for transit in small rooms
In SIVA's laboratory, we performed
- a substantial electronic modification regarding the addition of a second joystick for the nape control, serially connected to the one equipped,
- and the mechanical adaptations for the support and positioning of the 2 joysticks and the microswitches
Following functional tests, we realized Marco's impossibility to move the standard joystick correctly. it this was just moved on the back of his head and equipped with a small cushion instead of the cloque ball-grip We therefore constructed a small foam-lined wrapping headrest
The structure of the standard joystick is however not conceived to support an additional weight, even if small, therefore we constructed a small support for the headrest Moreover, in the practical realization, we took into account to facilitate the return movement of the joystick to the zero position
We took into account then the possibility to use the headrest support itself also as movement fulcrum, and to integrate it by adding proper springs for its report to zero, regardless from the structure of the joystick
In order to avoid raising and depression head movements, the headrest is allowed only two movements forward-backward and lateral
The headrest structure was realized with an aluminium strap, bent of a radius of 150 mm, with a tapped hole at its centre
Here a steel rod, of the overall length of 250 mm. was inserted and fixed, crossing the headrest support in its forward backward direction and ending with a second threading
The function of the latter is to support a ring inside which the joystick metal lever is inserted, free from the upper ball grip
By means of this construction. the extension of the head moves the headrest backwards and transmits a stroke of the same size to the lever of the joystick. that varies its inclination, thus controlling the final speed
A compression spring inserted onto the steel rod in an intermediate position between the headrest and the fulcrum support brings back the headrest into zero position
To facilitate such a movement, important also for emergency breaking, the spring has a relatively high hardness and is always kept in light compression by means of the insertion of a steel pin in a hole made between the fulcrum support and the joystick

A second steel rod parallel to the first, and integral to it, allows to greatly limit the inclination movements of the headrest
The two rods were inserted into two parallel holes made onto an aluminium parallelepipedon, supported by a brass circular base-plate.
Two small springs and an elastic pin, respectively fitted into a milling onto the circular base-plate and into the parallelepipedon, allow the return to zero of the lateral movements of the headrest.
The direction control takes then place by means of a lateral flection of the head, laterally moving the headrest.
This movement too is transmitted to the joystick in a similar manner to what described above.
In Marco's case the ratio the more correct for the distance between headrest, fulcrum support rotation axis and joystick must be near 1 2.1 (the distance between joystick and fulcrum must be multiplied by 1.2 to get the measure fulcrum / headrest)
Again on lateral position, but more forward and lower with respect to the headrest, near the chin, we installed two supports for the three sensors needed to run the wheelchair
The first one is a switch allowing to turn on the whole system. the second a knob controlling a relais simultaneously reversing the tension polarity transmitted to the two motors, the third a knob excluding the motors and putting the motors for bending and verticality in circuit
The trade name of the standard joystick used for the movement of the wheelchair is "Elettronico A/S"
It is equipped with two positions, UP and LAY DOWN
These two functions correspond to the variation of back . seat, footrests
The main assumption for our design of the electronic modifications was the necessary safety Marco is completely unable to vary by himself the position of the four limbs and the trunk
We therefore judged necessary to be able to easily cut out all the operation possibilities of the nape joystick, by means of the operation of the manual joystick.
For the production of the prototype I required the installation of a second box onto the wheelchair containing a double governor joystick
Moreover we requested the construction of the connections needed to operate the following control sensors
a a master switch for the on/off function of the whole nape electronic kit
b a shunt switch to reverse the tension polarity transmitted onto the motors (this allows reversing)
c a shunt switch to insert either the joystick or the two

microswitches that allow the operation of the electric motors for the functions UP LAY DOWN

Moreover, a little control panel for the on/off functions was provided in such a position to be easily in sight of the patient. Such a panel was equipped with

a a five led bar with the double function of showing that the nape kit is on, and the charge level of the batteries,

b a red led forward engaged

c a green led backward engaged

d a yellow led function UP / LAY DOWN

The main purpose of the electronic circuit, is to allow to operate the head controls independently from the manual ones and vice-versa, being sure that switching on the manual joystick the control circuits of the nape joy-stick are opened

The nape controls are possible by means of the master switch, only if the master switch of the Elettronica A/S is in OFF position

When nape controls are made possible, one can set the forward or backward control, by means of the FWD/BKWD switch

The I relais swaps the supply line cables of the nape joystick, thus allowing reversing

All functions can be choosen given that the wheelchair is not moving and that the joystick lever is in zero position

The signal MASTER ON from the control box is in fact at low tension when the wheelchair is moving, so the action of the FWD/BKWD switch would carry a low tension signal to the IC1 integrated circuit in active flip-flop configura-tion

The same applies to the CHANGE FUNCTION 2 switch. Finally, in its standard version, the Elettronica A/S has a protection to avoid accidental movements. If the master switch is put on ON while the joystick is not in zero position, the wheelchair does not move at all. To operate the motors it is necessary to go back to the zero position for a short while and then operate the joystick again

RESULTS

The construction of the prototype was meant for the actual possibility to use it by Marco, who at present, thanks to the practical realization of the *idea* and the many small modifications performed, manages to control the variations in position and to move around by himself, thus reaching a greater personal independence than before

Base criterion for our action was to search the highest construction semplicity as possible, and at the same time the realization of all the safety systems necessary to grant Marco and his family confidence

DISCUSSION

Adapting and installing the mechanic and electronic components required about two days

The training took about one hour, needed to explain the user the different functions of the components and to feel completely comfortable about the positioning of the different switches

Marco immediately started to drive the wheelchair, with a good control of the movements even in the relatively small space at his disposal

Construction costs for the prototype are about 6,500.00 USD for different materials, construction and installation of the second joystick, later modifications performed onto the first version

To this we have obviously to add the cost of the electronic wheelchair, about 10,500.00 USD in its standard version at this date

It is instead rather difficult to quantify the working time needed for the development of the described prototype

DISCUSSION

The referred costs can surely be reduced following a mass production, even limited, or avoiding to install a second joystick and using the one provided by the producer

In such a case the mechanic modification should take into account the extraction of the ball-grip of the joystick and the possibility to move vertically the box containing it; the electronic one, the installation of a master switch control-ling a relais for the polarity inversion of the motors

The relais must be installed just before the motors. In this case the mechanical costs are kept unvaried, while the electronic ones can be reduced to approx. 250 USD

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Massimo Ferrario
SIVA
Fondazione Pro Juventute Don Gnocchi
Via Capecelatro 66
20148 Milano
Italy

# MECHANICAL HEAD SWITCH RECLINE INTERFACE

Chip Fiske
Shepherd Spinal Center

ABSTRACT
The design of a head operated recline device as an inexpensive option for use with C3-5 level quadriplegia and select clients with cerebral palsy is presented. The device interfaces with the LaBac power recline system and is compatible with adjustments on the LaBac headrest. Custom variations of the device can be made to interface with other types of headrests.

## BACKGROUND

Persons with C3-5 spinal cord injuries need to recline or tilt for weight shifts. Some clients with severe cerebral palsy may also have the need to tilt for comfort and positioning. In some cases there is a need for an inexpensive head device which will operate the recline or tilt of the wheelchair. Other clients experience some discomfort with the commercially available head switches.

## STATEMENT OF PROBLEM/RATIONALE

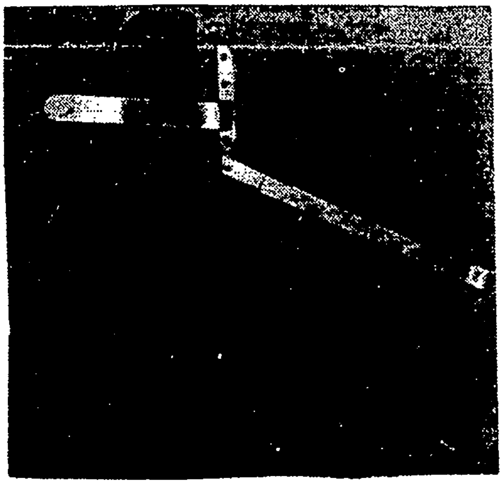
Individuals who use tape switches on the headrest are faced with certain dilemmas. These switches require an electronic interface box to operate the power recline system. The tape switches are expensive because they require an electronic box or interface. Additionally, some patients express discomfort on the back of the head where tape switches are attached. The mechanical head switch eliminates the need for tape switches. It attaches to the existing headrest and interfaces with the toggle switch that is standard with the recline system. Another advantage of the mechanical head switch is adaptability. The toggle switch can easily be remounted as an elbow operated switch or a leg operated switch. This is a tremendous advantage for quadriplegics who regain some arm movement.

## DESIGN/DEVELOPMENT

The concept for design started with a need for a link between the head and the recline toggle switch. First, the toggle switch was mounted on back of the LaBac headrest bracket at a right angle to the top plane of the bracket. Aluminum channel stock is then used to link the toggle switch with the headrest. This stock is attached to the top plane of the bracket using the existing adjustment knob hole and a 5/16 bolt. The rest of the head switch is customized according to the type of headrest used. The standard mount used is for the LaBac headrest. This consists of a fabricated aluminum channel angle bracket with holes drilled for adjustments up/down and forward/backward. Attached to the angle bracket is a U-shaped bracket made of 1/2 inch aluminum bar and Kydex formed to fit the shape of the headrest and the head of the person. T-foam is used on the ends of the U-shaped bracket for comfort. Precision is important when fabricating this device so that minimal movement of the person's head is required to activate the switch. To enhance the device, a small on/off switch can be installed in the toggle switch box to activate and deactivate the mechanical head switch.

## EVALUATION/DISCUSSION

The first person evaluated had a C-4 spinal cord injury. The mechanical head switch recline worked well. However, position on the head was critical as we found that contact with the U-shaped bracket could be lost when reclining in the LaBac 0-shear system. By mounting the bracket as low as possible on the top part of the head, this problem was alleviated. The next person evaluated was a C-5 injury and was a great success with the head switch. Finally we evaluated two pediatric patients. One had a C3-4 injury and the other had C4 level transverse myelitis. Both were using tilt-in- space power chairs. Tilt-in-space works well because the contact point between the bracket and the head does not change. In conclusion, the mechanical head switch recline can be used in many cases by following certain guidelines: use precision when fabricating the head switch and use careful positioning of the U- bracket on the head.



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ADDRESS
Chip Fiske
Shepherd Spinal Center
2020 Peachtree Rd. NW
Atlanta, Georgia 30309
(404)350-7721

P2.21

# TOWARD THE DEVELOPMENT OF AN ADJUSTABLE FORWARD TILTED SCHOOL CHAIR

**A. Shany, J. Bowles, G. Skidmore, S. Ryan,**
**The Hugh MacMillan Rehabilitation Centre**
**Toronto, Ontario, Canada**

**Abstract**

The objective of this project is to provide a functional seating solution for school children who use wheelchairs. Working posture as well as independent mobility and independent transfer to and from the chair are an essential combination of functions not offered by existing types of school chairs.

To create a chair which offers children the above characteristics, a prototype school chair was developed. It has an adjustable height to fit children ages 5-15 and an adjustable seat angle of 0°-10° forward tilt. The design also facilitates independent mobility through the provision of castors.

The prototype was evaluated with the assistance of seven students, their teachers and clinicians, in a classroom setting. The population included children with cerebral palsy, spina bifida and head injury. The children performed various class activities such as writing, reading, keyboarding, doing artwork while seated in the prototype chair at a variety of desks.

From the initial evaluation, advantages of the chair are: achieving an appropriate working posture, comfort of seating, independent self-positioning, ability to move about the classroom.

**Background**

In reviewing the activities of students in the classroom, it was found that students either transfer to a regular chair or remain in wheelchairs. No "standard" chair was used: a variety of plastic and wood chairs were common. Clinical team members found that functioning was inhibited and performance appeared compromised as a result.

School activities require seating postures different from those offered by a wheelchair. In a working posture, the body is reclined forward toward the desk and the hands should be able to function (writing, keyboarding, etc.). While occupied with these tasks, the student cannot easily use his / her hands or forearms to support the upper body.

Other areas of concern voiced in discussion with teachers and school therapists regarding the design criteria for a school chair included:

**The psychological effect.** In regular schools, self image among peers is extremely important for the student. Disabled children would like to sit just like other children, on a chair which is similar to other chairs yet having support and comfort as needed. Since they are in a sitting position most of the time, their position is usually lower than other children's position. Independence is a part of a child's social status; it is important to encourage independent functioning.

**Mobility.** The student with a physical disability needs, like other students, to be able to move within the classroom. The available classroom space is limited and obstacles make it difficult to manoeuvre. The smaller a chair is, the better. This also relates to the psychological effect mentioned previously; therefore the style and appearance of the chair must be considered.

**Comfort.** The student with a physical disability may spend much more time than the able bodied student in a seated position.

**Development**

Based upon the needs described above and upon research dealing with posture and proper characteristics of school furniture (1,2), a prototype chair was designed which included the following characteristics:

1) **Adjustable height** - Based upon ergonometric data, seat height is adjustable from 13.5" to 21.0". A simple mechanism enables the teacher to adjust the chair's height.

2) **Adjustable angle** - There are three optional positions for the seat angle: 0° (level), 5° or 10° forward tilt. Adjustment is done easily using the same mechanism as the height adjustment.

3) **Side supports** - Built into the chair's structure are side boards which function as hip supports and help the child maintain support in the chair. There are no forearm supports: these were found to be unnecessary due to the posture obtained.

4) **Mobility** - Four castors are provided at the base of the chair to facilitate mobility. Each has a built-in brake which can be activated either by foot or hand to help position and stabilize the chair.

5) **Cushion** - This consist of a plywood base and two layers of foam: 1/4" thick high density polyethylene foam and 1" low density foam. The seat cover is a high friction naugahyde, used to prevent sliding forward.

6) **Back support** - A minimal and flat back support is supplied, (8" high) with 1/4" high density foam, with the same finish as the seat cushion. Three optional positions allow for a seat depth of 11," 13," or 15".

7) **Appearance** - The chair is made of laminated plywood, designed to match other commercial work surfaces so as to create a working station. The lamination colour is grey; plastic trim is provided in a variety of colours as a custom accent to the chair.

8) **Options** - A 45° lap belt provides extra security.

The seven subjects chosen for the study presented with a number of diagnoses including: cerebral palsy (4), spina bifida (1), and head injury (2). Subjects were between the ages of 7-12 years. The subjects were able to: a) maintain their feet in supportive position; b) benefit from functional extension of the trunk that the chair imposed.

**Method**

A "pre-prototype" chair was built and critiqued by occupational therapists. Following their critique (different cushion, handles, built-in brakes), this version was modified to include their suggestions.

Before, as well as during the evaluation stage, the teacher and the teaching assistant were instructed in technical details such as height and angle adjustment. Reasons for and advantages of the forward tilted posture were fully outlined.

Each student used the seat for at least one week. Candidates were selected by the project occupational therapist, the class therapist and teacher. The chair was evaluated in grade 4-5 with children of 10-12 years of age, and grade 1-2 with children aged 7-8. During the first classroom placement only (grade 4-5), the children used the chair for more than two weeks each.

In both classes the children performed various class activities such as writing, reading, keyboarding, doing artwork while seated in the prototype chair, at a variety of adjustable desks.

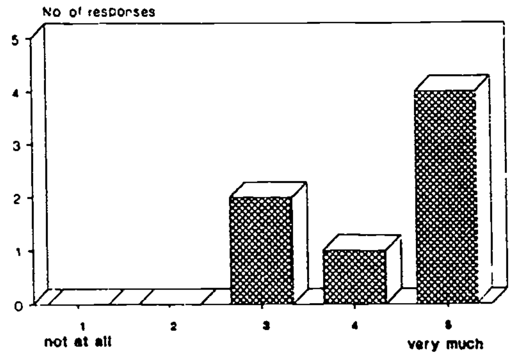


**Figure 1. Responses to the question: "Did the child feel comfortable in the chair? "**

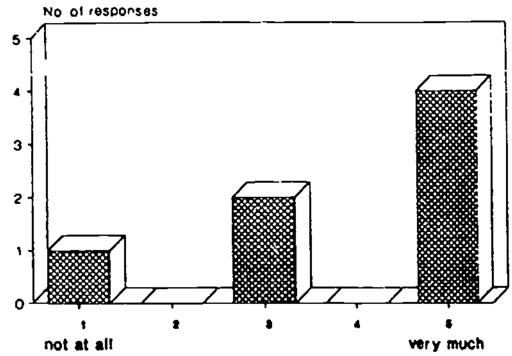


**Figure 2. Responses to the question: "Do you feel the chair improved the child's position?"**

**Results**

All children selected for the study willingly used the chair during their trial periods. The chair was used all day for intervals of 30-60 minutes. All students used the 5° forward tilt. (It had been recommended to start at 10°, and if such an angle proved too difficult, move to 5°). All responses regarding the appearance, weight and stability of the chair were positive. Results of the evaluation are quantified in Figures 1-2.

## Conclusions

Results of initial evaluation showed that advantages of the chair are: achieving an appropriate working posture; comfort of seating; independent self-positioning; ability to move more easily about the classroom. Comments from staff were related to: a) good functional posture, which was described as "upright positioning", "keeps the child's midline", etc., and: b) the ability to move around the classroom, seen as an advantage in all the evaluations.
Recommendations for improvement included: a need for handles when moving; a need for friction on the castors to prevent sliding on some types of floors; and a problem which arose among the younger children for whom the side boards of the chair were too high to fit beneath primary sized desks and/or tables. The need to continue the development was suggested. It may be necessary to produce two sizes of chairs, for children nominally aged 5-10 years and 10-15 years, because seating must allow for height adjustment which enables partial support as well as mobility.

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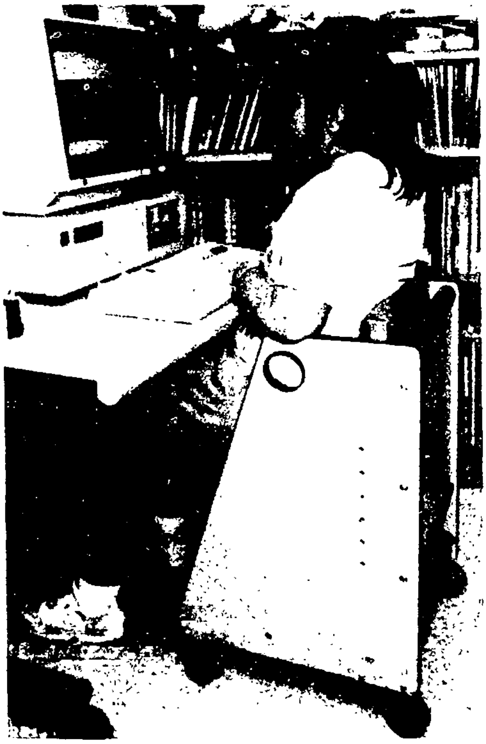

Arnon Shany
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Rd., Toronto, Ontario,
Canada, M4G 1R8

# The Lordosimeter: A New Method to Continuously Measure Lumbar Curvature in the Seated Environment.

Hannu Alaranta, Kevin P. Coleman, Steven M. Reinecke
Vermont Rehabilitation Engineering Center
University of Vermont

## ABSTRACT

A unique tool has been developed to overcome the problem of measuring lumbar curvature: The Lordosimeter. The purpose of this study was to build a device which can continuously measure lumbar curvature with subjects either standing or sitting and to validate the lordosimeter with templates and the Flexible ruler technique. Repeated testing with the templates of known curvature indicated a linear relation with accuracy to within 0.05 percent. For validation the lumbar curvature of twenty subjects were measured in five defined positions. Results indicate that there exists a straight line relationship between the output of the lordosimetor and the flexible ruler. The correlation coefficients for the relationship had a minimum of 0.96.

## BACKGROUND

A better understanding of the kinematics of the back in seated postures should provide insight into the relationship between posture and low back pain. Additionally, the ability to measure the lumbar spine curvature and pelvic orientation of a seated subject would provide the basis for improving seating, particularly in the work environment. However, present techniques for measuring pelvic motion and lumbar curvature are of limited utility when subjects are seated and leaning against a backrest, since their backs cannot be observed or accessed. At the Vermont Rehabilitation Engineering Center a unique tool has been developed to overcome the problem of measuring lumbar curvature: The Lordosimeter.

## OBJECTIVE

The purpose of this study was:
1) to build a device which can continuously measure lumbar curvature with subjects either standing or sitting;
2) to validate the lordosimeter with templates and the flexible ruler technique.

## MATERIALS

### Lordosimeter

The design criteria for the Lordosimeter required a noninvasive device that would continuously measure lumbar curvatures with subjects either standing or sitting. Practical considerations that affected the design of the device were the following:

1. The device would have to overcome the problem of measuring lumbar motion when a subject leans against a backrest;
2. It would be necessary to affix a transducer to the back, without it being affected by skin distraction;
3. Shear forces between the subject's back and the backrest (during movement) would have to be minimized;
4. The device would have to be both thin and comfortable, and could not affect normal motion;
5. The device could not be affected by pressure deriving from the force of the back against a backrest.

The Lordosimeter consists of several thin layers of material with an overall thickness of 5.1 mm. It is 25 mm wide and 230 mm long. It contains two strain gauges, that produce a change in resistance when either elongated or contracted. The outcome measurement is D.C. voltage. A lycra covering is used to minimize any adhesion to the back.

Before testing, the subject is fitted with the Lordosimeter. The base is attached at the sacrum at the level of the posterior superior iliac spine (PSIS) with surgical tape. In full flexion, the lordosimeter extends to T12. The top portion of the Lordosimeter is held in place against the back by a strip of fabric attached to the skin on both sides. This fabric "bridge" allows the device to slide under it and against the skin, therefore minimizing any skin distraction. As the subject's lumbar curve changes, the flexible ruler, held close to the back, measures that change.

## METHODS AND RESULTS

### Validation with Templates

To verify that the Lordosimeter gives a linear output for variations in curvatures, ten curved "templates" were fabricated. These templates ranged from a 1500mm radius of convex curvature to a 1500 mm radius of concave curvature. The Lordosimeter was placed on the template and compressed while recording the voltage. Repeated testing indicated a linear relation with accuracy to within 0.05 percent.

### Validation with Flexible Ruler

To validate the Lordosimeter a comparison to a well known technique was performed. The flexible ruler technique is the National Institute for Occupational Safety and Health (NIOSH) standard measurement technique for curvature of the lumbar spine. It is described fully in the "NIOSH Low Back Atlas of Standardized Tests and Measures". We used a modified technique described by Burton (1986). The examiner locates the spinous process of S2 and T1 and marks the locations. The flexible ruler is placed against the subject's back and conformed to the subject's lumbar spine and the landmarks are marked on the ruler. The shape is then transferred to a recording form. Tangents are drawn on the curves at the S2 and T12 points. The angles formed by the intersection of the tangents are measured.

Twenty volunteer subjects were recruited, 10 females and 10 males.

For validation the lumbar curvature of each subject was measured in five defined positions:

1. Sitting (spine in full flexion)
2. Prone with pillows under the stomach
3. Flat prone
4. "Semi-cobra"
5. "Full cobra" (spine in full extension)

The position "Semi-cobra" is the arched-up position assumed lying prone on an examination table while supporting the weight of the trunk with the elbows on the table and humerus perpendicular to the table, pelvis as low as possible. "Full Cobra" is the maximal arched-up posture with elbows extended fully.

Measurements were randomized and the values of the Lordosimeter and the flexible ruler were recorded at the same time in each position.

Results indicate that there exists a straight line relationship between the output of the lordosimeter and the flexible ruler. The correlation coefficients for the relationship had a minimum of 0.96.

**CONCLUSIONS**

From this study we have seen that it is possible to measure lumbar curvature with the lordosimeter. The method has been shown to be accurate when compared to the standard measuring procedure, the flexible ruler technique. It is hoped that this device will now allow us to measure lumbar curvature in the seated environment.

**LITERATURE**

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Address:

Vermont Rehabilitation Engineering Center
One South Prospect Street
Burlington VT 05401

# Development of Indoor Wheelchair Mainly Made of Wood

Hiroshi Nashihara, Katsuzo Shizukuishi
Department of Industrial Design Tohoku Institute of Technology
Sendai, Japan

## Introduction

If wood were to be used industrially as the primary construction material of wheelchairs, wood should impart many available properties to them. The ratio of intensity to specific pravity of wood is higher than that of steel. Wood has superior heat retaining, hygroscopic and sound absorbing properties. When a wooden wheelchair is used in the home, it would better blend with the interior environment. It will have a more interior, soft and warm image.

We worked from this perspective. We have developed an indoor wheelchair mainly made of wood, since 1988. This development is near the practical use stage now. In this report, we explain this research, and clarify the problems for practical use.

## Objectives

This development has two aims. A wheelchair is a device to aid walking and it is a chair. As the first reuisite, this wheelchair must have the suitable functions and efficiencies to be fitted to the interior environment in the home and must have a good interior image. On the other hand, woods are produced in the respective districts and are a renewable resource. If a region were to have a woodworking shop, wooden wheelchairs for the indegenous handicapped may be produced locally. Meanwhile, if the already widely managed producers of wheelchairs at present should introduce wooden, handcrafted products, they may produce wooden wheelchairs, as a usual product line. That is, to say, the second aim is the establishment of a production method.

## Wood Working

We have applied the laminated forming technique to produce wooden parts. This technique uses 10 - 15 sheets of laminated wood about 1.5 mm - 2.0 mm in thickness attached by bonding with adhesive and pressed in wooden molds. Beech was used. Beech has superior bending properties. Its specific gravity is 0.7. Forming pressure is about 15kg/cm². Urea resin was used as the adhesive. After forming, the parts are finished by plane or a file, or especially by lathe. This work was done on an experimental basis at our woodwork studio in our college. For parctical use, this work willhave to be done at woodworking shops that use the laminated forming technique in Japan. This laminated forming technique is generally applied to chairs, tables and furniture now.

## Outline of Wheelchair

We started this reserch in 1988. We made an original wheelchair in 1989. This trial had many problems for practical use. Even since, improvements were made one after another. Up to this point, we have made it over three times on an experimental basis. Every time we made it, we experimented with its use with the aid of several hadicapped people. We found many points of possible improvement. Now, we have approached to practical use stage. We are clarifying production design specification.

The outline of our wooden wheelchair finally produced is as follows:

(1) Wooden parts by laminated forming technique are frame, hand rim, arm rest, seat back, and seat bottom. Driving wheels and casters are not wooden parts

and they are available on the market.

(2) The size of the wheelchair is 970 mm in length, 615 mm in width, 880 mm in height. It is capable of making a small turn. Its size will be fitting for an interior space. Bottom seat height is about 430 mm at the center of gravity. Its height is fitted to a bed, toilet, dining table etc.

(3) The wheelchair couldn't be folded up. But, driving wheels can be removed. The wheel chair will be able to load small in a car.

(4) Seat bottom and seat back are constructed with laminated wooden plates and cushions. They will give to the physically handicapped good quality and comfort. Width and length of them is determined by body size.

(5) The frame size is decided in a sitting posture. The seating angle is decided in a light working posture. According to the physically handicapped persons' requirements, seating angle can be adjusted from 92 · to 115 ·.

(6) Driving wheels and casters are joined with the wooden frame, comprising several metallic parts. the functions and efficiencies on driving will be satisfied.

(7) Wooden hand rims have a circular shape. They are joined directly to driving wheel rims by screws. Their sectional shape has been investigated under the condition of driving fitness. It is not a simple circle. Their shape is finished by lathe or numerical control machine.

(8) Total weight is about 15 kg now. From now on, lightweight models will be investigated. We suppose that its weight will finally come to about 12 kg.

Applied to the physically handicapped

We have felt from several trials that wooden wheelchairs will be demanded most strongly by elderly people having conditions or diseases of the aged (in Japan). Many specifications are determinined by their physical condition. Especially, the aid points of contact are provided. Elderly people comprise on increasingly large segment of Japan's population. This wheelchair will satisfy their strong demands in the future.

Strength of Woodenparts

We tested the strength of a laminated wooden frame and compared it with the strength of a metal pipe frame. Test items are below.

a: Standard material testing of wood; tention, compression, bending, shearing, and sparing tests.

b: L-shape frame breaking test.

c: T-shape frame breaking test.

As a results, we determined that a 30 mm × 30 mm sectional piece of laminated wooden frame is slightly stronger than Φ22 mm and t 1.2 mm of stainless steel pipe. We determined the sectional size of the wooden frame was 30 mm × 30 mm.

Result

We have developed an indoor wheelchair mainly made of wood. As a result, we are on the threshold of the practical use stage now. The wooden wheelchair was finally found to have suitable functions and efficiencies to fit the interior environment of the home, and to have a good interior image. Further, this wheelchair imparts a kind smoothness and warmth to physically handicapped peoples' environment.

## Discussion

Wood such as beech, as we obtained, are readily available materials for wheelchairs. Now we are testing the durability of the trial wheelchair finally produced. We suppose the strength and durability of wooden parts will not be poor and practical use will be feasible. The problem for practical use is production cost. The laminated forming technique is rational for industry, but it requires skill because the properties of wood such as beech are not uniform, and the finishing process requires craftsmen's skills. We estimate the cost of this wheelchair as about 2,000 dollars in Japan. Another problem for practical use is the establishment of a production method. We have joined a widely managed maker of wheelchairs with a widely managed woodworking shop in Japan.
For a while, this production mothod will be developed. In the future, we want to construct a production method such that a local producer can make the wheelchair using woods in his area to supply it to local handicapped people. From now on, investigations such as this will be necessary.

## Acknowledgements

This research was provided for by the Ministry of Educaiton Japan, the Department of Industrial Design of the Tohoku Institute of Technology and Nissin Medical Industries Co. LTD.

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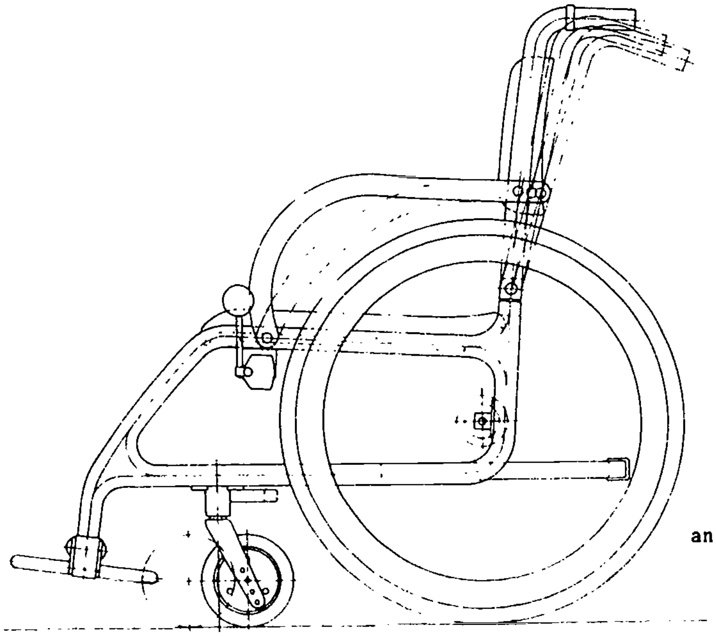


A wheelchair made on an final experiment basis

P2.24

# Multi-Functional Rehabilitation Wheelchair Base

Ray Rego - Larry Gray
Rehabilitation Technology Center
Indianapolis, Indiana

## Abstract

An effort has been made to develop a wheelchair mobility base that deals with the specific problems found in rehabilitation seating of the non propelling population. Interference from cross frames, push tubes, armrests and footrests has been eliminated by making them part of the seating system rather than part of the wheelchair base.

## Method

The mobility base is comprised of a rigid square tube truss frame, composite wheels, oversized tires and extra heavy duty brakes. Armrest and footrest are part of the seating system rather than the mobility base.

## Construction

The frame is a truss configuration made of square tubing. We have made models in both steel and aluminum. The frame is a rigid welded unit that has a powder coated finish. Multiple axle placements allow 12 to 20 inch wheel diameters to be used. Eight inch casters are standard. Turning casters can be in the front or in the rear.

Since the chair is for non propellers, we were able to use composite wheels with oversized pneumatic tires. This combination has superior strength and ride cushioning.

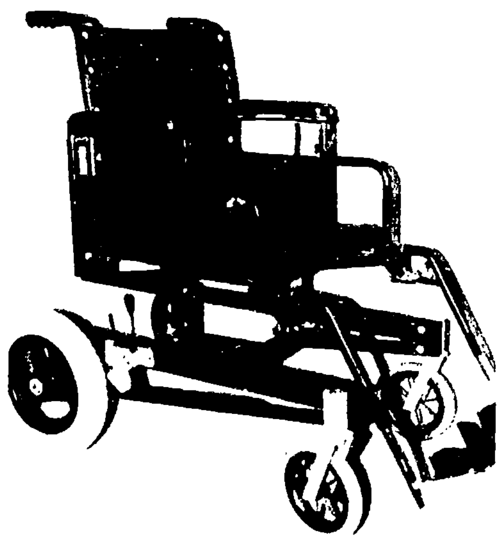
The brake we have chosen is a rugged spring release model with a rubber contact shoe for a more positive engagement to the tire. This brake has a long lever for easy use by the caregiver.

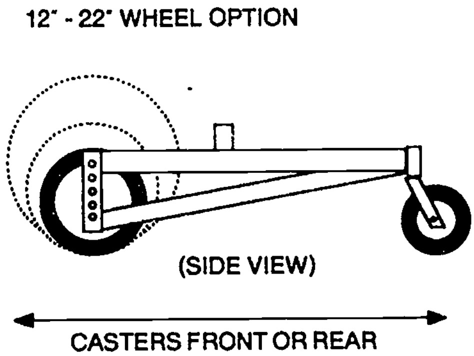
The base has a single post configuration that allows for the quick change of seating systems. Wheelchair, van seat, pediatric or custom seating systems can easily be mounted on this base. Seat heights as low as 10 inches are possible.

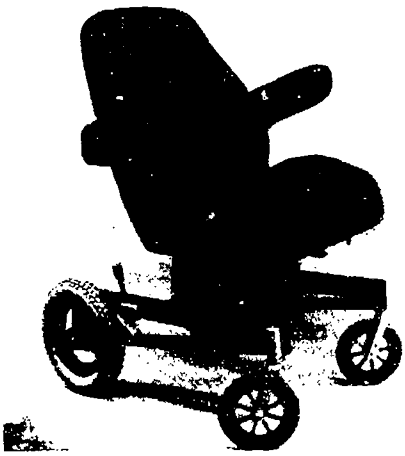
We have also used this base for angle-in-space configurations. The rigid frame and low center of gravity make this and excellent combination.

## Conclusion

Further design and development is planned for meeting the continuing needs of the disabled population. This style of base has eliminated many of the factors that have traditionally caused interference and problems with seating and positioning goals. There are many other possibilities we intend to pursue in the future.





Acknowledgment

This work was supported by the Indiana Department of Human Services.

Ray Rego - Larry Gray
Rehabilitation Technology Center
6862 Hillsdale Court
Indianapolis, Indiana 46250

P2.25

# Multi-Adjustable Lateral Hardware

Ray Rego
Rehabilitation Technology Center
Indianapolis, Indiana

## Introduction

We have developed a simple hardware system to deal with the reoccurring problem of lateral pad placement. This system allows for easy knob adjustment in both the up/down and in/out modes. When combined with an "I" back, this hardware allows great flexibility.

## Method

The system is composed of a vertical slide rod, a locking block and a horizontal slide rod that also connects the lateral pad.

The vertical slide rod is a flat stainless steel bar that attaches to the back of the seating system with only two "tee" nuts. This gives good strength and maximum up/down movement.

The locking block is a machined block that locks the movements of both slide rods by the use of a friction knob. This allows easy placement of the lateral pads by the therapist without bolts, tee nuts or wrenches. Permanent attachment, if desired, is a simple matter of drilling two locking holes and inserting spring pins. This permanent status can also be reversed.

The horizontal slide rod is also made of stainless steel. It has countersunk holes for flush mounting lateral pads on one end. This mounting gives support to the entire lateral pad making for a very strong mounting. The other end of this bar goes through the locking bolt and gives a great deal of in/out adjustment.

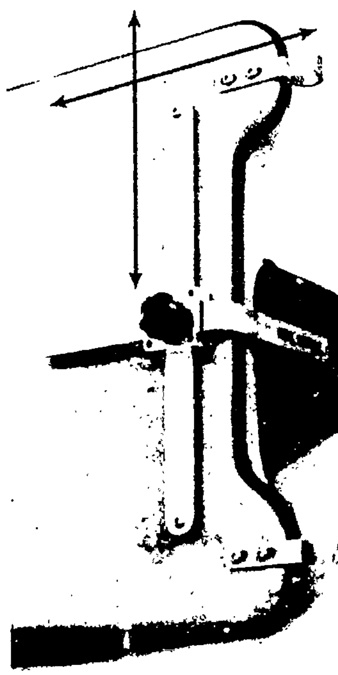
## Conclusion

This device gives maxim adjustment in a manner that is ea to work with and eliminates t need for massive amounts of "te nuts, bolts or wrenches to ma adjustments. This is of particul benefit in situations of changi client populations.

## Acknowledgment

This work was supported by t Indiana Department of Hum Services.

Ray Rego
Rehabilitation Technology Center
6862 Hillsdale Court
Indianapolis, Indiana 46250



P2.26

# Attachment Device for Seating Components

Ray Rego
Rehabilitation Technology Center
Indianapolis, Indiana

## Introduction

The reoccurring problem of changing component placement and attachment has been one of the most frustrating to therapists and technicians in building seating systems. Tee nut placement is limiting and time consuming and difficult to change. This has led to the development of an extruded track system that allows unlimited change of components and straps.

## Method

This system is composed of an extruded aluminum double track bar that mounts to the back of a seating system. This bar is attached to the seating system with 2-3 1/4-20 tee nuts and 1/4-20 bolts. Once attached, it allows unlimited attachment for seating components such as drop hooks, lateral pad hardware, anterior straps and custom or standard hardware items.

Attachment to the track bar is accomplished with special square nuts that slide into the track bar. These are for standard size bolts 1/4-20, 1/4-24, 10-24 and 10-32.

The spacing of the tracks on the track bar is one inch center to center. This fits most of the commercial hardware available today.

The track bar is extruded of high grade aluminum and is black anodized to be as inconspicuous as possible. It has a profile height of approximately 1/2 inch. The design is extremely rugged and easy to use.

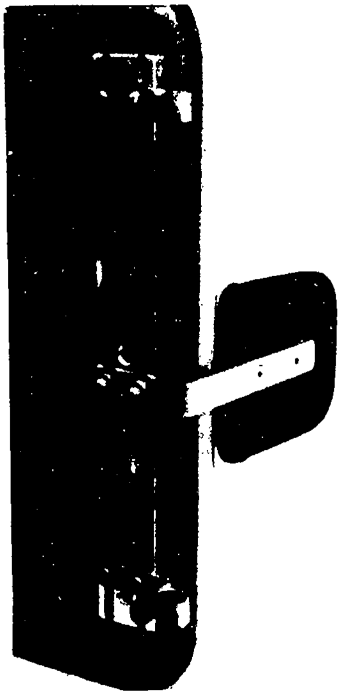
## Conclusion

This is a simple device that can make the once frustrating task of changing components a simple matter. Clinicians dealing with a changing population would find this system a useful tool.

## Acknowledgment

This work was supported by the Indiana Department of Human Services.

Ray Rego
Rehabilitation Technology Center
6862 Hillsdale Court
Indianapolis, Indiana 46250



P2.27

# Powered Assisted Mobility for Pre-School Children with Severe Motor Impairments

Patti Place
Daniel D. Lipka
Family Child Learning Center

**Abstract**
This poster describes a project in which preschoolers with multiple handicaps were given the opportunity to use specially adapted battery-operated riding toys for independent mobility.

**Background**
The purpose of this poster is to present information on a study designed to provide opportunities to control specially adapted commercially available powered mobility toys to young children with cerebral palsy and/or multiple handicaps who are not independently ambulatory. The techniques used and the results obtained in this study will be presented in an attempt to increase awareness of mobility options for young children.

**Procedures**
This poster provides information on an innovative and relatively low cost way of giving children who are severely handicapped the opportunity to independently move around in and explore their environment. Battery-operated riding toys (available at toy and department stores) were adapted to meet each individual child's seating and postural support needs. Adaptation of the switch interface (e.g., changing from foot switch to hand switch) was accomplished after the appropriate vehicle for each child was determined. Appropriate adaptations were determined through observation, videotape analysis and discussion with the child's motor specialist. All of the children were provided opportunities to practice operating the vehicles at appropriate times throughout their morning preschool sessions (e.g., to/from classrooms, to/from gym). Half of the children also took the vehicles home on weekends and vacations. Data were collected on distance traveled, the amount of time the child spent in the toy, the amount of time the motor was activated and the "driving" skills the child was acquiring. Baseline and weekly probe sessions were conducted on a designated course to measure each child's progress. Specific intervention procedures were consistently provided between probe sessions. All of the target children quickly acquired the ability to independently activate the switch and move the toy short distances. The rate of acquisition of sustained activation for long distances and steering skills has varied among children.

The poster includes baseline and intervention procedures, data sheets, graphs of child performance, and pictures of the vehicles outlining the adaptations.

**Summary**
Currently preschool children with severe handicaps are not routinely given the opportunity to use powered mobility devices (e.g., wheelchairs) due to factors of cost and rate of growth. They are therefore denied the opportunity to independently interact with and explore their surroundings. Commercially available battery-operated riding toys specially adapted to meet the postural support needs of children who are handicapped provide a more viable means of giving children independent mobility and a chance to participate in typical childhood activities.

**Acknowledgements**
Miller's Rental & Sales of Akron Ohio for modifying the toys for postural support and switch activation.

Patti Place
Family Child Learning Center
90 W. Overdale
Tallmadge, Ohio 44278
(216) 633-2055

# COMPARATIVE EVALUATION OF MAJOR BRANDS OF LEAD-ACID BATTERIES

Christian Lavanchy
ECRI
Rehabilitation Technology Program
Plymouth Meeting, Pennsylvania, U.S.A.

## Introduction

The performance of modern powered wheelchairs and scooters has improved with the development and availability of lower-power electronic components and better-designed motor-control circuits. While these newer motorized vehicles provide users with more freedom than ever before, a poor choice of battery can limit wheelchair or scooter performance.

While some studies have provided generic information about the sizing and selection of lead-acid batteries for power wheelchairs and scooters (5, 1), no information is currently available for consumers regarding differences between battery models on the market. A comparative evaluation of lead-acid batteries is one project that has been completed under the auspices of a cooperative Rehabilitation Engineering Center (REC) grant from the National Institute of Disability and Rehabilitation Research (NIDRR).

## Background

The prospective purchaser of lead-acid batteries for powered wheelchairs or scooters is often faced with a bewildering array of battery models, battery types (sealed or conventional electrolyte), and battery specifications. As a result of common myths about battery behavior and a widespread lack of knowledge about battery characteristics among powered-vehicle users and those that prescribe wheelchairs and scooters, poor choices of battery are common. Such choices are especially likely if purchasing decisions are based primarily on the lowest price: a battery may be lower priced at the time of purchase, but may not be economical in the long term. Poor battery choice can result in frustration and sometimes in costly frequent replacement, since many batteries cost in excess of $100.

## Objective

To help fill the gap in knowledge about battery selection and to provide consumers with a comparison of batteries available from major manufacturers for powered wheelchairs and scooters, a comparative performance evaluation of lead-acid batteries was performed.

## Methods

Thirteen deep-cycle lead-acid battery models were obtained from 5 major U.S.manufacturers and distributors for the study. Two battery sizes were tested in the evaluation, 22NFs and U-1s, representing the majority of batteries used in power wheelchairs and scooters. Battery models included in the study were of both the sealed and conventional design and ranged in price from $72.85 to $160.00. These batteries were tested for capacity, service life, energy density, and quality of design.

Battery capacity was tested using a test method adapted from the University of Virginia (UVA). UVA determined a series of currents to be drawn from a battery during a cycle that is representative of the typical current demands on the batteries of wheelchairs during outdoor use. In our capacity test, the cycle had a duration of 1 min and was repeated until each battery was discharged to a predetermined level. Battery voltages were recorded as each current was drawn throughout the test, and battery voltage versus time curves were generated from the data.

Using the same test method as for the battery capacity test, the 22NF batteries were discharged and recharged repeatedly until they could no longer provide more than one half hour of service. Each cycle of discharge and charging took place over a 24-hour period allowing adequate time for batteries to fully recharge. Battery discharge times were recorded for each cycle, and discharge times versus usage cycle were generated from the data.

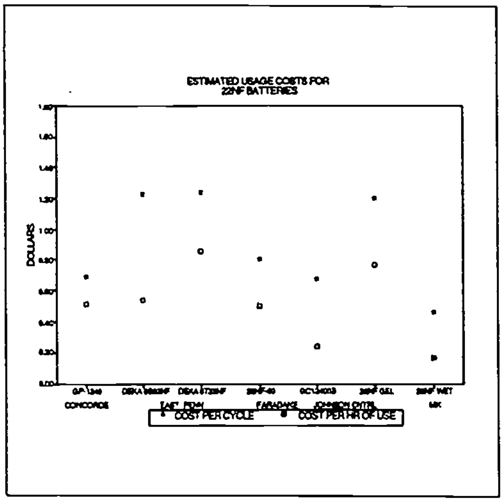
The typical energy densities of the batteries were determined by computing the watt-hours each battery was able to produce in the battery capacity test and dividing the values by the battery's weight. Batteries that have higher energy densities (watt-hours/kg) are preferred because, in theory, they can provide more hours of usage without contributing as much to the total weight the wheelchair must carry.

Each battery was also assessed for its quality of construction and how its design affects care and maintenance. Features such as carrying handles and maintenance, including the ease of replenishing water when necessary, were considered in this portion of the study.

## Results

Battery capacity results obtained in this study relate to how long a powered wheelchair or scooter user can expect to operate vehicles with the battery models tested. Surprisingly significant differences in hours of usage were found, with some models providing as much as twice as many hours of operation as other batteries of the same size.

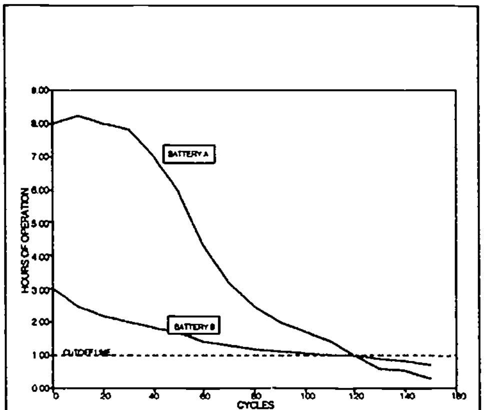
Results of the service-life test can be related to the number of days of use that the powered-vehicle user can expect to get out of each battery model if the batteries are heavily used each day. Real battery cost can be computed from the results of this test in terms of the cost of the battery per hour of use. Service life was found to be distributed over a wide range, and when purchasing prices of batteries was considered, the price per hour of usage for the 22NF batteries ranged from 16 cents to 85 cents.




Energy densities and quality of construction and design results were found to be significantly different, but were perceived to be secondary to the results from the two previous tests when making purchasing decisions.

**Discussion**

Several battery characteristics should be considered when making a purchasing decision. It appears that the two primary characteristics are the battery capacity and service life. The ideal battery will provide many hours of reliable operation over many days of usage at a reasonable cost. Unfortunately, it is not always possible to find batteries that meet all of these criteria. Some batteries exhibit very high capacities early in their life, but the capacity rapidly drops off with continued use. Consequently, while two battery models may provide the same number of days of usage (cycles) before they are replaced, one battery may provide far more capacity over its useful life than the other. The hours of use versus cycles of service curve and a consideration of the battery price may be the most useful information when choosing batteries. With these curves, the user of a powered wheelchair or scooter can quickly see how the battery capacity will change over the useful life of the battery and can estimate how many months to expect between battery replacements.




BATTERIES WITH IDENTICAL SERVICE LIVES AND VERY DIFFERENT AVERAGE CAPACITIES

From this study, it is clear that the price paid for a battery should not be the sole justification for a purchase. Moreover, users should consider their battery requirements in addition to costs per hour of usage when choosing. For example, if the powered-vehicle user only expects to use the wheelchair or scooter for an hour a day, primarily indoors, almost any of the batteries tested will suffice, and the cost per hour of usage should become a prime consideration. In contrast, the user who requires many hours of vehicle usage each day and may use commercial aircraft for travel, is better off selecting a sealed battery that can provide long hours of usage throughout its service life.

Below is a list of some factors specific to the user that should be considered before purchasing:

o How difficult is it to obtain the desired model?

o How many hours per day, on average, will the vehicle be used, and will the use be sustained or intermittent?

o Will the wheelchair or scooter be used mostly indoors or outdoors? If outdoors, over what type of terrain will it be driven?

o How much does the user weigh? (The total weight of the wheelchair will influence the range of travel, and, thus the required battery capacity.)

o What electrical accessories will be powered from the same batteries?

o How practical is it for the user to add water to conventional electrolyte batteries and provide other care and maintenance?

o Does the user fly when traveling?

o How expensive is the battery?

Additional information and a summary of the specific findings of the evaluation will be presented at RESNA.

**Acknowledgements**

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Christian Lavanchy
ECRI
5200 Butler Pike
Plymouth Meeting, PA 19462

# Design-For-Handicapped Projects in a capstone Design Course

Wayne W. Walter and Richard G. Budynas
Mechanical Engineering Department
Rochester Institute of Technology
Rochester, New York 14623

## Introduction

In order to introduce more design into our mechanical engineering curriculum, a two-course capstone design sequence has been recently established. In this non-traditional course, three to five students work as a design team on open-ended projects to develop an idea into a working prototype. Within the past year, in cooperation with local agencies for the handicapped, three projects were initiated which involved devices to assist handicapped children and adults. A description of the design course sequence and the development of these projects is the focus of this paper.

## Background

RIT's Mechanical Engineering Department recently revised its curriculum to include a required twenty week, two-course capstone design sequence in the senior year of our five-year cooperative education program. Groups of three to five students work in design teams in an environment which approximates an industrial setting. Emphasis is placed on teamwork, and developing good oral, written, and interpersonal communication skills. Teamwork is carried out in an independent mode which fosters self-discipline, self-reliance, and self-confidence. This approach provides an opportunity for close cooperation with industry and with local agencies for the handicapped.

In the first ten-week course, student teams complete the final design of a mechanical system. At this point, each team has performed the appropriate engineering analysis addressing functionality, performance, cost, and manufacturing including detailed engineering drawings to build the prototype. A final report containing this information is submitted together with an oral presentation to the class, faculty, and participating outside organizations. Each student is required to keep a bound logbook of their day-to-day activities. All library research, meeting minutes, work on design alternatives, calculations and engineering analyses are recorded in their logbook. Students find that a well-maintained logbook becomes a welcome reference when writing their weekly and final reports.

In the second ten week course, the same students work together to build and test a working prototype. Non-working prototypes are deemed unacceptable, and some redesign work is often required to make their systems work. The required deliverables for the second half of this course sequence are the working prototype and written interim and final reports. The final oral and written presentations will include a performance test/demonstration of the prototype. Students are expected to spend considerable time in the material processing shop during the build phase of their projects, and in the labs during the testing and verification phase It is e[illegible]ted that test fixtures will need to be designed and built as part of the testing phase, and this should be included in the PERT schedule of events for the project.

Recently, some projects have involved building assistive hardware for handicapped individuals. This has become a source of satisfaction to those students and faculty who have been involved in meeting the needs of these individuals. Three recent design-for-handicapped projects will be briefly described here.

## Motorized Rocking Chair

This device was designed and built by students for handicapped children at the Mary Cariola Children's Center, in Rochester, New York. Many children with developmental disabilities have difficulty holding their heads upright. Using a rocker helps strengthen neck muscles, and is therefore an important therapy. Secondly, handicapped children often have tense muscles which can be relaxed with the soothing motion of a rocking chair. Many of the children at the Mary Cariola Center, although teenagers, are in many respects more similar to small children or even infants. It is possible to rock a baby in our arms, or a small child in our laps, but this is not possible with a child who is nearly the size of an adult. The rocker provides a practical solution.

At the time that the students started this project, the Mary Cariola Center had a chair built by a volunteer that was motor driven with a variable stroke and speed, but due to the nature of his design, both speed and stroke were also a function of the child's weight. The center asked that the students design a new chair with variable speed and stroke that would be unaffected by the weight of the child in the chair.

Figure 1 shows a schematic of the chair during the conceptual design phase which uses a four-bar suspension (parts #1-4) to provide a gliding motion to the user, rather than a rocking/pitching motion. The chair is driven from an eccentric wheel attached to a DC electric gear motor (part #5) through a second "four-bar" linkage (parts #5-8). Variable speed is provided by lengthening link #5 (changing the attachment position of link #6 on the eccentric wheel).

Figure 1 also shows how the system was computer modeled. Note that the model does not contain revolute joints exclusively as does the real system. Instead, spherical and universal joints were employed to prevent the system from being mathematically overconstrained. The model showed the motion of the chair to be smooth and gentle as required for the children who would be using the chair.

## Motorized Rocking Platform

When the rocking chair was built and subsequently tested at the Center, it did not meet all of the customer requirements. Its gliding motion, in particular, was not as pleasing as anticipated. For this reason, a second student team undertook a follow-up project to design and build a motorized platform whose motion duplicates that of a rocking chair. The platform will be capable of accommodating a variety of therapeutic furniture in use at the Center. Children sitting in their furniture can be placed on the platform for rocking. Both head-to-toe rocking and side-to-side rocking will be provided. This project is currently in the build phase. A sketch from the conceptual design phase is shown in Figure 2.

## Wheelchair for Standing Applications

Another recent project worthy of note involved the design and construction of a wheelchair that will raise a seated person to a standing position, and yet still be mobile. This project was done with the assistance of the Monroe Developmental Center in Rochester, New York. The intent here was to allow the user to stand for purposes of being eye level with a client, making a copy at a copier, working at a large machine tool, writing on a blackboard, and numerous other everyday applications. The mechanism devised is gas spring assisted, and allows the wheelchair seat and back to move upward with the user as the user pulls backward on the arm rests. The small upper handwheels can be rotated by the user in the standing position to move the larger wheels. A sketch is shown in Figure 3.

## Conclusion

The projects described herein have been satisfying to all who have been involved. They have addressed the real human needs of handicapped persons, and have been a great way to meet the course requirements.

## Acknowledgements

Our thanks to all the mechanical engineering students who have worked on these projects. Our appreciation also goes to Mr. Dan Bock, Mary Cariola Childrens Center, Rochester, New York; and to Mr. Bill Flynn, Monroe Developmental Center, Rochester, New York, for their support.

Wayne W. Walter, Ph.D., P.E.
Mechanical Engineering Department
Rochester Institute of Technology
Rochester, NY 14623

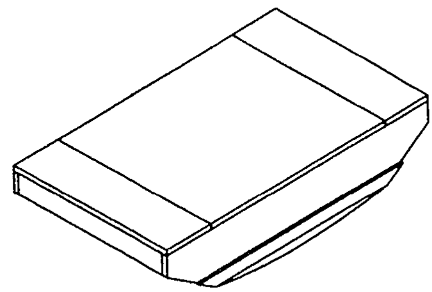

Figure 2: Motorized Rocking Platform

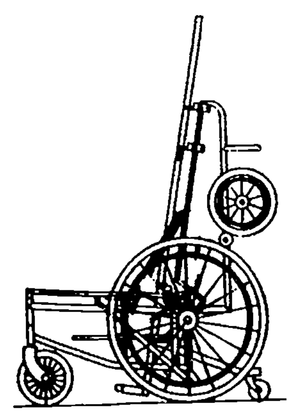

Figure 3: Wheelchair to Raise the User to a Standing Position

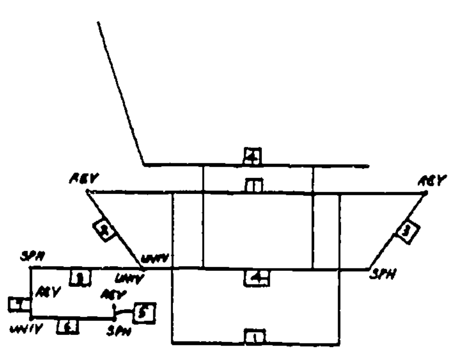

Figure 1: Motorized Rocking Chair for Handicapped

P3.2

# MAKING PHYSICAL FITNESS EQUIPMENT ACCESSIBLE TO ALL

Abir Mullick
State University of New York at Buffalo

**Abstract:**

The need for maintaining physical fitness for all people can hardly be overemphasized. This need is yet more crucial for those who are older and disabled. Even though there exists substantial evidence that exercise and movement is capable of preventing the deterioration of physical capabilities and motor control, the use of most physical fitness equipment poses considerable barriers and risks to these two groups. This paper discusses the need for physical fitness and an analysis of problems encountered by these groups in using exercise equipment. It also presents a case study of one piece of a equipment and how a modification was designed to improve its usability and safety for all.

**Background:**

Wellness related research has indicated that physical fitness is an important component in ensuring a physically-active and illness-resistant lifestyle for older people and those with disabilities. Regular physical activity can help these people maintain, repair and improve their body. A regular exercise program is capable of improving heart and lung endurance, muscle strength, and flexibility. Experts confirm that high proportion of age-related decline is actually the result of inactivity and improper diet. Studies have shown that regular exercising can slow down the decline of age-related neuromuscular and sensorimotor capabilities. Exercise and movement has a positive impact on physical and mental well-being of people with disabilities and exercising can retard certain changes that once were thought to be inevitable among these people.

Two basic types of exercise equipment are available in the market: 1) setups for lifting free weights, and; 2) variable resistance machines. These exercise devices are adjustable, and enable an exerciser to experience a variety of conditions based on their needs and capabilities. A quick review of this equipment indicates that the sole purpose of all available equipment is to provide vigorous weight training. The equipment is primarily for muscle building. Traditionally, this equipment has been used by the young and the beautiful with no consideration for those people who are older and disabled. Even though these people realize the importance of exercise, they are usually discouraged by comparison with the physical prowess of their younger counterparts (Burdman, 1986).

There is a great scarcity exercise equipment for older and disabled people. The few that are available in the market are essentially modified versions of traditional variable resistance machines. These devices focus primarily on the needs of people with mobility impairment and have been retrofitted for wheelchair users. Even though these devices work very well for the intended users, they are user-specific devices and pose problems for other non-wheelchair users.

Most existing equipment ignores human factors considerations for older and disabled people. Operation of these equipment by these people can be unsafe for them. For example, bench pressing necessitates pushing and balancing a heavy weight in the air. Those with weak arm strength and poor shoulder joints are likely to loose control of the balancing weight and injure themselves. It is not uncommon for people to black out under heavy physical stress and drop the weight on their chest. Hazards of freehand weight lifting are built into variable resistance equipment and integrated weight lifting equipment. For example, a leg curl and extension machine can cause knee injury to those with poor knee strength and others who exceed their tolerable limit. All exercise equipment puts considerable physical demand on users, and none of them incorporate safety mechanisms to prevent injuries resulting from overreaching.

**An Accessible Exercise Device**

This is a case study on making a variable resistance exercise device accessible to all people. The device is called a lat machine, and it assists in the development of upper body muscular strength. A request to make a lat machine accessible came from an individual who is a lower limb amputee with stubs extending only a couple of inches below the hips. The individual, we'll call him Jeff, is in his 40's, and is dependent on use of a wheelchair for mobility within and outside his home. Weight lifting has been his primary means of maintaining physical fitness. He has a professional quality lat machine at home. Both he and his 'able-bodied' wife, say Kathy use the machine. However, due to its design shortcomings, Jeff has been compelled to exercise at a supervised gymnasium.

Lat machines provide controlled levels of upper body exercise resulting in muscular development of arms, shoulders, neck, and chest. Exercising involves lifting weights in a seated position, by pulling down and releasing an overhead bar connected to a column of weights. Generally, the weights lifted exceed the user's own body weight, and in the absence of a proper seat, the inertia from the release of weights tends to lift the user out of the seat. The body is kept in place by anchoring the knees under a horizontal bar. The safety and operational implications resulting from this practice are: 1) it necessitates the use of legs, and is inaccessible to many with poor or no leg strength, and 2) the knees are prone to injury during times of lifting heavy weights. Since Jeff has virtually no legs, he cannot use the machine independently at all.

The objective of this project was not to develop a user specific assistive product that would meet the exclusive needs of the individual client. Since in a way we are all disabled, the ergonomic issues surrounding accessibility of this device, centered around understanding the general limitations of his wife as well as specific handicaps facing the person with a disability. Any design modification was aimed at benefiting both people.

Assistive devices for individuals with disabilities, are indispensable tools that allow independence in mobility, communication, and personal care (Levy, 1983). As an alternative, the philosophy of universal design is based on the belief that all environments need to be accessible by all people including those with disabilities. Universal design incorporates the ergonomic considerations of consumers with disabilities without compromising either usability or desirability by non-disabled consumers (Ringwald, 1988). These products can be aesthetically pleasing, cost effective, and improve the quality of life for everyone. They reduce the need for high cost, difficult to obtain and unreliable assistive devices. Making a product usable by people with disabilities lowers the performance demands of all users. This, in turn, makes it easier for everyone to use.

In case of the lat machine, it was perceived that a product capable of independent use by Jeff would make the product easier and safer to use by Kathy and others. The design issues surrounding modification of the lat machine included:

1. determine what features of the machine restricted its access to the disabled user,
2. incorporate ergonomic issues that were capable of enhancing safety and easy operation of the machine by all users including people with disabilities,
3. identify what design features were critical for meeting the exercise needs of the user.

For example, Jeff wanted the seat to turn 180 degrees. This was expected to assist him in developing the pectoralis (frontal muscles) and the trapezuis (back muscles). Several innovative seat designs were studied. Their usefulness were evaluated on the basis of how well they secured an individual without use of legs, how easy they were to operate and how difficult it was to turn around. For example, a shoulder support possibility was explored. This was later abandoned because it was cumbersome and there was inadequate space to accommodate a support system between the neck and the raised arm (during times of weight release).

The most promising results were found in securing the pelvis on the seat by means of an adjustable belt around the waist (see fig. 1). This method offered the following benefits:

1) utilized a strong bone structure for weight transfer,
2) allowed direct and vertical transfer of forces,
3) freed the legs, and
4) eliminated stress around the knees.

The proposed design is a non-user-specific seat, based on the anthropometric dimensions of a large person (see fig 2). The new seat makes the machine usable by all people including the elderly, beginners, and those with poor leg strength (see fig 3).

The prototype is fabricated in reinforced fiberglass, and is easy to maintain, repair and replace. For wheelchair users, the seat facilitates easy transfer. There are several general safety features built into this design. Two of the most important are a concave seat surface and a safety belt for better seating security. All these features benefit any user of the device. The design offers easier operation, improved performance, and greater safety for all.

**Discussion:**

This project demonstrates a universal design approach for exercise devices. Only one part of the original design needed to be modified to provide extensive benefits for all users. Most assistive products are a reaction to failures in conventional design and are "band-aid" solutions to more complex problems (Steinfeld, 1989). The high cost

Fig 1

Fig 2

of assistive products is due low demand and the perception that these are "specialized products" to meet the needs for only a few. Generally developed to suit the needs of those making the purchase decision (e.g. the therapists), rather than the "consumers" using them, these products are often clinical in their appearance, and create user alienation, social distance and stigma.

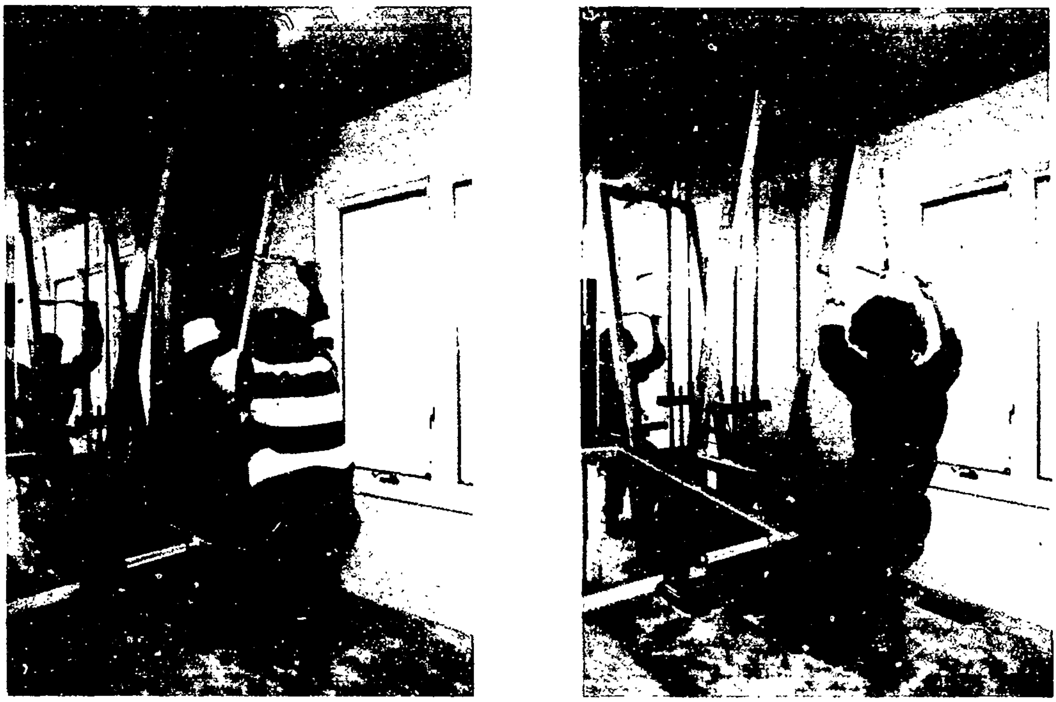

Fig 3

The capabilities of older and disabled people are more diverse than they are similar. For example, increasing age produces even greater variability in physical and cognitive capabilities (Ostrow). Custom design of assistive products for these people will pose a major burden to product designers, manufacturers and ultimately consumers. Thus universal design makes good design and economic sense. Universal design products can provide empowerment for persons with disabilities by maximizing independence. These products can not only be functional, but they can also be beautiful (Steinfeld, Mullick, 1990).

## Conclusion:

It should noted that the seat design described here is only a first step towards solving the problem. The design needs to be further developed and tested to accommodate a greater range of users. Proper material for the seat needs to be explored and manufacturing techniques for mass production need to be investigated. The usability of the lat machine by the older and disabled adults needs to be examined in depth.

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# Teaching About Simple Switches: Not So Simple

Roger O. Smith, MOT, OTR
Gregg C. Vanderheiden, Ph.D.
Trace R&D Center
University of Wisconsin-Madison
Madison, WI

**Abstract**
Over the years, it has become increasingly clear that the switch is a simple transducer which profoundly affects access to assistive and rehabilitation technology. It has also become clear that, while the switch may be a simple transducer, its application is quite complex. Switch selection must be made from an array of switch types and styles. Switches have a wide variety of physical features ranging from differences in size, to pressure required, to the degrees of freedom for activation. Switches also come in combinations, including multiple switches and keyboard designs. Wide varieties of electronic parameters now exist to modify simple switch closure. All of these advancements have made simple switch use not so simple. The understanding and application of switches has, in fact, become a significant challenge to technology educators, in the classroom and in fieldwork settings. This paper highlights this problem, introduces pedagogical resources, and discusses the usefulness of this approach.

**The Problem**
In the field of assistive techrology, switches are considered among the simpler of the technologies, but this can be deceptive. While it is true that the use of switches for adaptive toys was introduced many years ago, and simple switch construction brought many of today's technologists into the field, the superficial simplicity of switches and switch application can be misleading. In the areas of augmentative communication and computer access, for example, switches have become quite complex. Electronic parameters that a technologist must understand to optimize switch use include delay times, recovery times, bounce times, hold times, repeat times, etc. An example of such a multi-parameter system is the AccessDOS software (Novak et al., 1991). Resources to help technologists step through switch and control evaluation also indicate the complexity (Lee & Thomas, 1990; Smith, 1990). A technologist considering the use of a switch or multiple switches has many dozens of inter-dependent variables to consider, ranging from the electronic parameters mentioned above, to switch site placement, to the physical attributes of the switch as system (e.g, size, pressure, excursion, feedback, etc.) Academic and fieldwork instructors of this technology are challenged to convey the increasingly complex set of information to students.

In our university-based technology training programs, we have tried to respond to this challenge, but have encountered two pedagogical barriers. First, there is no standard, straightforward listing of switch types and parameters. While excellent resources are available, educational materials have tended to be specific to certain technology applications, and have therefore been limited. More generic and complete resources are needed. Secondly, when switch parameter concepts are presented in written documents, they are often difficult to understand. Many switch characteristics are temporal in nature, and are therefore not easily comprehensible when presented verbally.

**The Strategy**
An educational approach was developed to address these difficulties in teaching concepts about switch application. First, we assembled a list of switch characteristics. We then organized this information into a taxonomy of switch parameters called the *Switch Parameter Checklist*. Figure 1 shows the main headings of this Checklist. As can be seen, a range of switch use features is included. Figure 2 shows the detail under one of the main headings.

To formulate this checklist, we reviewed currently used terminology and attempted to standardize the terms used. The Lee & Thomas manual (1990) on control of computer-based technology for people with physical disabilities was a key resource, as this document describes generic terminology for control systems. Also, using the expertise of a Technology Interface work group comprised of several experienced computer access and augmentative communication practitioners, the checklist was reviewed, elaborated, and refined.

Secondly, to overcome inadequacy of solely verbal presentation of information, we developed graphics to illustrate each of the switch parameters. Figure 3 shows samples from the *Switch Parameter Snapshots*.

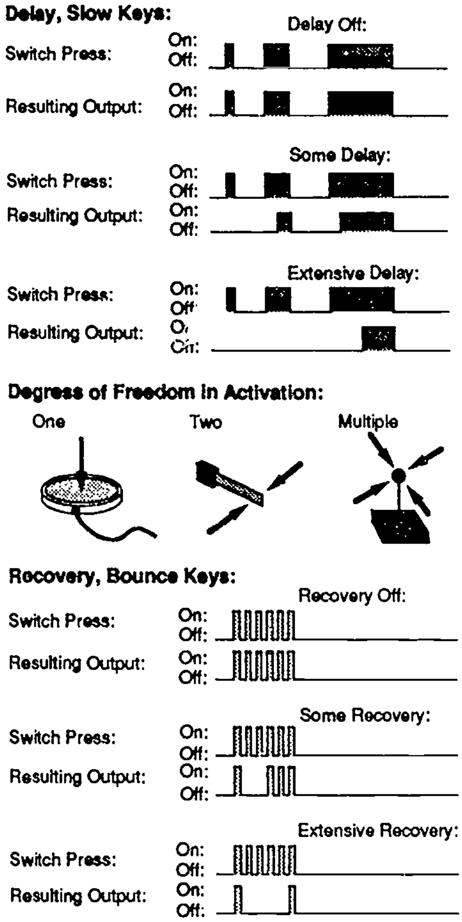
**Figure 1**
Headings of *Switch Parameter Checklist*

Electronic Parameters
Physical Characteristics
Feedback
Functional Features
Locational Variables

**Figure 2**
Electronic Parameters Section of
*Switch Parameter Checklist*

Switch Resting (closed, open)
Delay Rate
Recovery Rate
Repeat Rate
Averaging/Filtering
Pulse Only
Timed On
Latched
Signal Transmission mode
(pressure, light, ultrasounds, etc.)

**Figure 3**
**Examples from Switch Parameter Snapshots**




***Discussion of the Switch Parameter Checklist and Switch Parameter Snapshots***

In the past, we have taught switch parameters in classroom, laboratory, and fieldwork instruction, in a "catch as catch can" fashion. In our technology training programs over the past two years, however, we have begun using a more and more defined list of switch characteristics and parameters. The *Switch Parameter Checklist* and *Switch Parameter Snapshots* have been formally used this year in several ways. First, instructors used the checklist as a prompting system. Checking the list has ensured that all concepts are being covered. Second, the *Switch Parameter Checklist* serves as a set of learning objectives for students, and a study guide for examinations. The students mark off concepts as they master them. These documents have been helpful both instructors and students to standardize a knowledge base and performance competencies.

Several limitations in using these documents have been observed. First, no standard terminology and definitions for switch parameters and characteristics have yet been universally accepted. While these documents provide consistency and help standardize our training programs, and may well benefit other curricula, this specific set may not be optimal for everyone.

Also, although students are acquiring some basic knowledge regarding the different considerations in using switches, they still need information about the best methods for setting the adjustable parameters. The adjustable switch parameters all interact, and changing one parameter influences the settings of the others. Very little research has been performed investigating these relationships and optimal settings of switch parameters. Students and clinicians new to the technology interface area, as well as the field generally, need more research on this topic. Until more empirical research can be performed the switch application process will continue to be based on the clinical judgement, experience and intuition of those applying switches.

Finally, these two documents cannot stand alone. They are only paper-and-pencil educational resources. They are not an optimal educational format by themselves. Obviously, hands-on clinical experimentation with switch parameters and characteristics is more desirable for learning the application of these concepts. While these two documents serve as teaching tools and a method for mastering basic information, the process for learning the psychomotor skills needed for applying switches remains a hands-on process.

**Implications**

The *Switch Parameter Checklist* and *Switch Parameter Snapshots* are targeted to be teaching tools to fill a gap that is widening because of advances in technology. As a by-product, however, these lists may have other uses. As a comprehensive list of factors which affect the usability of switches, they form a theoretical taxonomy. This taxonomy is testable by empirical research. Also, as the assistive and rehabilitation technology field moves beyond optimizing systems through clinical intuition, we need to research which variables are most important, and how to set them to provide the best access for people with disabilities.

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Smith, R.O. (Ed.). (1990). *Sample course guide for an introductory course in rehabilitation and education technologies.* Madison, WI Trace R&D Center, University of Wisconsin-Madison.

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Roger O. Smith, MOT, OTR, Trace R&D Center, S-151 Waisman Center, 1500 Highland Avenue, Madison, WI 53705-2280

# Modified Nintendo Controller: An Application of Integrated Controls

Kevin M. Caves
Rancho Rehabilitation Engineering Center
Rancho Los Amigos Medical Center
Downey, CA

## Abstract

Technological advances in power mobility controls have made it possible to use the wheelchair input device (e.g. sip and puff, joystick) to operate other devices. A standard Nintendo game controller was modified to interface with a wheelchair equipped with integrated mobility controls. The modification allowed two children to control movement of the game characters using the wheelchair's input device control, and to control the two "fire" buttons using two switches mounted to either side of the jaw. Once set up, minimal instruction was required to teach the children how the system worked. Because they were accomplished drivers, so familiar with the sensitivities of their wheelchair controls, they were immediately successful.

## Background

Ivar is a 9 year old boy who had a spinal cord injury (C-2 level) in June, 1990, resulting in complete quadriplegia. Keyon is a 12 year old boy who had a spinal cord injury (C1-2 level) in February, 1990, also resulting is complete quadriplegia. Both boys are ventilator dependent, wear orthotic body support jackets with built-in head supports, and have minimal head motion. Both boys also use sip and puff controls to independently drive power wheelchairs. The chairs are equipped with mobility controls which allow the sip and puff control to operate as the input device for other technologies as well.

## Objective

Rehabilitation Engineering was consulted by Recreation Therapy for modifications that would allow children with high level spinal cord injuries operate a Nintendo video game system.

## Approach

A search was conducted to determine if a commercially available device could be obtained which the children could operate. Two devices were found and obtained for evaluation: The Hands Free* controller from Nintendo of America, Inc., and the Turbo Sip/Puff Joystick from KY Enterprises.

With the Hands Free controller, the user controls movement on the screen (left, right, up, and down) with chin control joystick, and a separate sip and puff switch to control the start and select buttons as well as the "fire" buttons A and B. The KY Enterprises controller uses a mouth held joystick to control movement with an integrated sip and puff control to operate the A and B buttons. Game start and select is controlled using two micro switches mounted on the left and right side of the face.

Both of the commercially available joystick controllers required too much head movement for either boy to use effectively, although one of the boys was successful with a Turbo Sip/Puff Joystick which was modified for use with the tongue.

If a wheelchair has appropriate electronics, the input device (joystick, sip and puff) can be used to operate other devices. As stated above, both boys have a wheelchair with these electronics, called an integrated control system. This allows the wheelchair input device to act as a switch to another device. Generally these integrated systems have the capability to control four switches at a time, one switch for each of the four directions: forward, left, right, reverse.

To use most Nintendo games, the user needs access to six switches simultaneously: the four directions and the two fire buttons. Using an integrated control system will only allow access to four switches simultaneously, so to use the integrated system at least two more switch sites and switches need to be identified. For total independent use (start and select), a total of eight switches need to be identified.

A standard Nintendo controller was purchased and modified to interface with the boys' Everest and Jennings Marathon power wheelchair's Dufco electronics accessory device port. This controller uses the chair's sip and puff input device to control movement on the screen, and two TASH Microlite switches, mounted using flexible gooseneck tubing on either side of the chin, to control A and B buttons.

At the time the paper was submitted, the children could not control the start or select buttons. A planned electronic modification will allow a third switch positioned under the chin to act as both the start and select buttons. Additionally, an infrared Nintendo controller has been purchased and modified to allow a wireless connection between the user and the Nintendo game.

Results/Discussion

Once set up, minimal instruction was required to teach the boys how the system worked. Because they were accomplished drivers and familiar with the sensitivities of their wheelchair controls, they were successful immediately. One occupational therapist reported a note increase in self esteem in one of the boys because he able to operate the game on his own. Since the success with the Nintendo, the children have been using integrated controls for other activities, for example Morse code input to a computer and using battery operated toys.

The use of integrated power mobility controls offer certain individuals opportunities otherwise unavailable to them. In this case, the use of integrated controls allowed access to a video game at a competence level close to their able-bodied peers.

Acknowledgements

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The author would like to thank the following people for their assistance and support with this project: Julie Helgren, Paul Meadows, Gail Brubaker, Faith Kaneshiro and especially Keyon and Ivar.

Hands Free Controller
Nintendo of America, Inc.
P.O. Box 957
Redmond, WA 98052

Turbo Sip/Puff Joystick
KY Enterprises
Custom Computer Solutions
3039 East 2nd St.
Long Beach, CA 90803

Kevin M. Caves
Rancho Rehab Engineering Program
Bonita Hall
7601 E. Imperial Highway
Downey, CA 90242

* Nintendo and Hands Free are registered trademarks of Nintendo of America, Inc.

# The MARLArm

David Altman, Inventor and Helper of people
Lincoln, NE 68508

Abstract
This paper will describe and address the question of how an individual with a severe disability adjusts the height and rotational angle of his or her computer monitor with the use of a switch. The switch mechanism can range from a pneumatic sip and puff switch to any type of micro switch.

## Introduction

**MARLA**rm (Mechanically Actuated Rotary Linear Adjustable Arm) is a device that will allow a person with a physical limitation to adjust his or her computer monitor independently. I recently read an article eloquently stating, "a person in a wheelchair doesn't have access problems because the person is in a wheelchair; the person has access problems because the local movie theater doesn't have a ramp." If you sit back in your chair and think about this for a moment you will realize the validity of this statement. If our designers, engineers, and creative inventors would consider the needs of all people when exploring research and development, most of the products they design could be used by persons with disabilities. There will come a time in our life when we will all experience some sort of disability, some not as severe as others but never-the-less we will have trouble performing a task in our daily lives that was once accomplished with ease.

Technology has literally exploded in development over the last five years to facilitate independence for individuals with disabilities. The **MARLA**rm is a piece of assistive technology that will allow an individual with a severe disability to adjust his or her computer monitor with the use of a switch. The **MARLA**rm allows adjustment of the monitor to accommodate seating needs and lighting issues.

## Design & Description of the MARLArm

We have all heard the quotation, "NECESSITY IS THE MOTHER OF INVENTION." Webster defines the word necessity as "Absolutely required, indispensable, needed to bring about a certain effect or result, unavoidably determined by prior circumstances or conditions." Many of the inventions we use today are base upon this nine letter word.

I have found all types of monitor arms and stands that adjust manually but none that will automatically adjusts with a switch. Below, in Figure 1, is a picture of the **MARLA**rm (Mechanically Actuated Rotary Linear Adjustable Arm).

The prototype of the **MARLA**rm is made entirely of stainless steel. The CRT, or monitor, will sit on a u-shaped platform. The platform base will accommodate about 90% of the standard monitors on the market, with a base of approximately thirteen inches. The platform can be custom made to fit oversized monitors. I have designed the arm to carry monitors that weigh anywhere from 15 to 55 pounds. Underneath the metal u-shaped platform lies the linear actuator. The linear actuator is electric and is responsible for the rotary angle adjustment of the monitor on a horizontal plane of the x-axis. This device was intended for use in home or industry, any type of linear actuator, electric or pneumatic can be used. Actuation design would become more in-depth using pneumatic in an industry setting. The platform and linear actuator will be attached to a dual metal fabricated arm. The arm is made of square stainless steel tubing and it uses the mechanical advantage of four bar linkage. This arm structure is not new. It is actually similar to the construction of the human arm. The human arm has two bones that are connected to the joint. The radius and the ulna are connected to a hinge joint which is connected to the humerus.
There is a second electric linear actuator that is located underneath the double bar linkage. This allows the user to adjust the monitor in a sagittal plane on the y-axis. The linear actuator is run electrically by a power supply. Again depending on where this device is used, an electric or pneumatic actuator can be utilized.

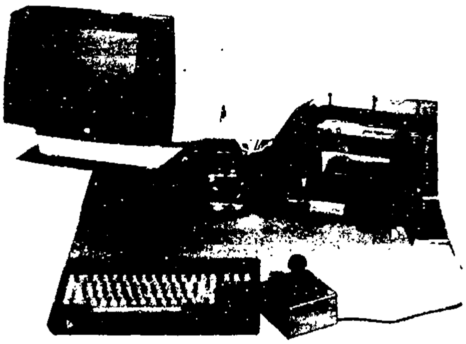


Figure 1

This assistive technology device can be attached in many different ways to a work surface. I have chosen to incorporate a u-shaped standard clamping mechanism to secure the **MARLArm** down to the work surface. A monitor can weigh anywhere from 15 to 55+ pounds. Therefore the MARLA arm should be securely fastened to the work surface.

Most any switching mechanism can be adapted to operate the **MARLArm**. I have chosen to run the MARLA arm with a four-way joystick. The switching interface is easily adaptable to a dual or four-way sip and puff switch. With the **MARLArm** I want to illustrate that persons with severe physical limitations can have the capability to adjust his or her computer monitor independently.

## Control Interface

Control devices can be connected to the MARLArm using a 9-pin, joystick-style connector. It is wired with an industry-standard configuration (as defined by the Trace Center and others). This is to allow standard joystick, sip and puff switch, or combination of four single switches (using a commercially available adaptor) to be easily connected and used to control the movements of the unit.

The control devices are electrically isolated from the motor circuits by control relays. This permits the use of a wider variety of control devices, protects the user from dangerous electrical currents, and permits the use of a fail-safe control system hierarchy.

The control logic is designed with safety in mind, using a pre-set lock-out hierarchy. If multiple switches are activated at the same time (as might occur with some input devices when the user and/or object accidently pushes the controls), this arrangement only allows the safest movement to occur. If the UP switch is one of multiple switches activated, the unit will move up. The order of dominance of the other switches is ROTATE LEFT, ROTATE RIGHT, AND DOWN, see figure 2. In situations of multiple switch activations, this hierarchy results in movements which usually position the equipment away from the user, and moves the unit down only if DOWN is the only switch activated. Control interface design by Jeff Krutz, ME; Lincoln, NE.

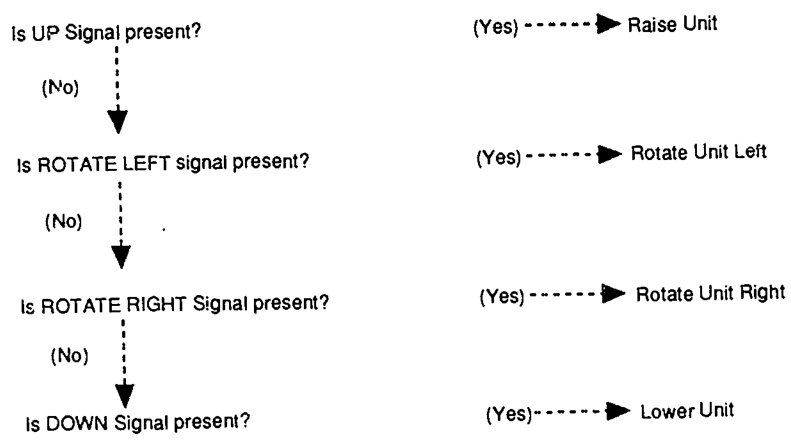
## Future Plans

I am presently working on making the **MARLArm** fully adjustable. The user will not only be able to adjust height and rotational angle, he/she will be able to adjust tilting and arm swing. The arm swing adjustment will allow the arm to swing closer or farther away from the the user. Future plans for the control interface will include the use of scanning and sequencing logic to allow full control of the device using any combination of one to eight switches.

## Summary

The **MARLArm** is an assistive device that helps create independence for a individual who has some severe functional limitations. This arm has many applications other than adjusting a monitor in 2- 4 directions. The **MARLArm** can be connected to a bed and used as a feeding device. The applications are endless. As an inventor and a person who has a strong commitment to help improve the lives of individuals with disabilities through technology, I believe that technology can help only 40% of the problem, the other 60% goes to people's attitudes that restrict some individuals in having an equal chance in

**Control System Hierarchy Diagram**




Given a combination of signals, the signal higher in the sequence will dominate, inhibiting the actions of signals below it.

**Figure 2**

life. I want to end with one last thought by Jack Ried, a human resource executive, who says: "A handicapped person - given the proper tools and support from an organization-will overcome the debilitating characteristics of his or her handicap and will become equally as productive as someone who is not handicapped."

## Recognition

I would like to thank Ward Enterprises of Lincoln, NE for donating the Micro Computer Table, fabrication & materials. I would also like to thank Warner Electric, Marengo, IL for donating Linear Actuators and Jeff Krutz for donating his time to help design the control interface of the MARLA™. Without the help of these individuals, the MARLA™ would have only been a conceptual idea.

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David Altman
Adaptive Device Systems
1311 Claremont Street
Lincoln, NE 68508

P3.6

# A Programmable Light-Tracer

Dominic P.K. Cheng
Rehabilitation Engineering Centre
Hong Kong Polytechnic
Hung Hom, Hong Kong

## Abstract

The Programmable Light-Tracer is a portable device to make learning the motor skills required for writing fun. It consists of a matrix of 21 x 20 light-emitting-diodes(LEDs), a light-pen and a control box. The learner has to follow a blinking LED with the light-pen to complete a pattern. Each light traced is rewarded with a beep and a pattern completed is rewarded with an interesting picture and a tune. Ten patterns are built-in to teach the rudiments of writing. Other patterns can be composed with the keypad on the control box. A Pattern Composer software for IBM-PC-compatibles allows a therapist to compose, store and retrieve patterns with ease. A composed pattern is transferred to the light tracer via a printer port.

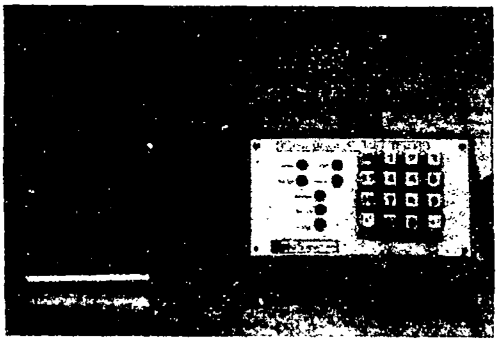


Fig.1 Programmable Light-Tracer

## Statement of the problem

The paper and pencil approach for learning to write may not work well for the handicapped with poor motor control or mental deficiency. Is it possible to have a device which makes learning the motor skills required for writing fun?

## Rationale

The light-tracer is analogous to a lettering-book. A light-matrix replaces the paper and a light-pen replaces the pencil or pen. A pattern is displayed on the light-matrix which is traced by the learner with the light-pen. A lettering-book indicates the direction of writing by an arrow. The order of lights turning on is a more vivid indication. An advantage of an electronic aid is that an immediate reward, such as a beep, can be provided for each light traced.

A PC-based solution is possible. A pattern can be shown on the computer screen for a user to trace with a light-pen. The advantages of this approach are the unlimited patterns that can be produced and the possible use of colour and sound. The obvious disadvantages are the cost of a PC and that target institutions may not have PCs, especially portable ones. Other disadvantages are the possible damaging effects of low level ionizing radiation from computer monitors (CRTs), wrong orientation of the screen and the need to protect the screen and light pen from children.

A robust portable programmable light-matrix system with preprogrammed patterns, a light pen and a printer interface seems to offer a good compromise at present. The light-matrix and light-pen can easily be made quite robust and there is no ionizing radiation.

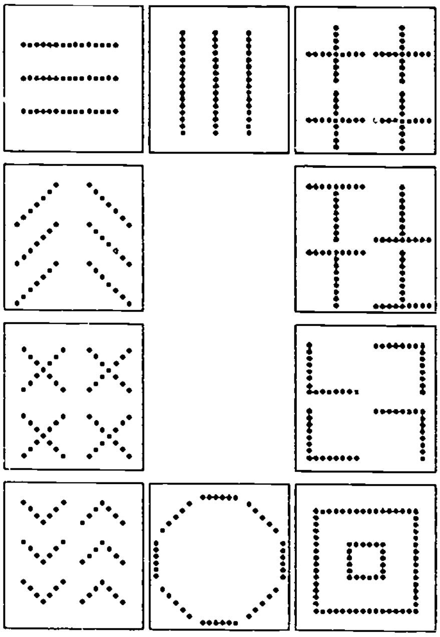


Fig.2 Pre-programmed patterns

## Design

Programmable light-matrix

The programmable light-tracer consists of a light-matrix, a control box and a light pen (Fig.1). A Motorola MC68705R3 single-chip micro-computer is used as the controlling element.

Within the limit of the matrix size, any pattern can be displayed. For example, the minimum matrix size for numbers and English alphabets is 5x7. More than one symbol as well as better looking symbols can be shown with a larger matrix. For reasons of flexibility, aesthetics and readily available commercial 5x7 LED-matrices, twelve 33mmx53mm devices are used to form a 21x20 matrix. The matrix is enclosed in a box made of PVC with a translucent top of red acrylic.

The rudiments of writing can be represented by horizontal lines, vertical lines and slant lines. 10 patterns, formed by simple combinations of these elements, are stored in the micro-computer (Fig.2).

Read/write memory (RAM) external to the micro-computer is included to allow programming of patterns using the built-in keypad. A computer interface enables downloading of patterns from a PC to the RAM via a printer port.

Able-bodied persons use their hand to position a pen so that it is in a correct angle for writing. To make this task less demanding for the handicapped learner, the angle of the tip of the light-pen is adjustable. The photosensor of the light-pen is recessed in a protective PVC collar.

Modes of operation of the light-tracer and pattern sources are as follows: -

Operation mode:
normal, demo, program, external
Pattern source:
pre-set, keypad, external

The demo-mode is used to show the user what has to be done. A pattern is first selected by entering its numeric ID. When the ENTER key is pressed the lights turn on one after another until the whole pattern is displayed.

In the normal-mode, the first light in the selected pattern turns on and blinks. The learner has to position the light-pen over the blinking light to obtain an audible reward, in the form of a beep, and to activate the next light in the sequence. When the learner completes a pattern, a tune is immediately played and a picture similar to that shown in Fig.3 appears a few seconds later to replace the completed pattern.

In the program-mode, a pattern can be composed using the keypad. Each light is specified by entering its row and column addresses. This is a time consuming process and the pattern is lost when power is removed from the light-tracer. Once a pattern is programmed, it can be used for demonstration and tracing.

The external-mode is used to download patterns from an external PC. Again, once a pattern is transferred from the PC to the light- tracer, it can be used for demonstration and tracing.

## Pattern Composer

To ease the problem of composing, storing and retrieving patterns, a Pattern Composer was developed for IBM-PC-compatibles. This software displays a matrix and user instructions on the screen (Fig. 3). Composing is fast and easy. Cursor-keys are first used to select a light. Function-keys are then used to turn the light either on or off, and to insert lights within a sequence if desired. Each light to be turned on is displayed as a 'smiling-face-character'. As in the light-tracer, a demo-mode is used to run the 'lights' on the screen. Once the therapist is satisfied with the pattern, it can be saved on disk and transferred to the light-tracer.

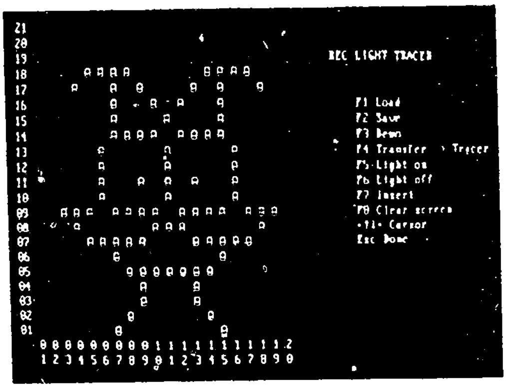



Fig.3 An animal figure composed using the Pattern Composer

## Evaluation

One light-tracer has been in use in a special school for over a year. Children like the blinking light and beeping sound. it has been treated as a toy.

## Discussion

The programmable light-tracer has been developed as a robust, portable device for training the motor skills required for writing. It aims to make learning to write fun and safe. Initial reactions has been favourable but only further evaluation in the field will indicate whether this approach is useful for the assumed task.

## Acknowledgements

The technical help from C.S. Leung is greatly appreciated. This work was supported by the Royal Hong Kong Jockey Club

Dominic P.K. Cheng
Rehabilitation Engineering Center
Hong Kong Polytechnic
Hung Hom
Hong Kong

P3.7

# BLINKSWITCH: NEW TECHNOLOGY FOR RELIABLE BLINK ACTIVATED COMMUNICATION AND CONTROL

Jeffrey J. Jerome
VME Technologies, Inc.
Baltimore, MD

## ABSTRACT

A highly reliable voluntary eye blink detector has been developed which overcomes the problems associated with blink activated communication and control. BlinkSwitch dramatically reduces errors in detecting voluntary blinks while simultaneously reducing the time involved in setup and adjustment. While the BlinkSwitch uses the conventional methodology of measuring changes in infrared (IR) signals reflected from the eye to detect blinks, this technology is improved by unique digital signal processing techniques. These techniques analyze and differentiate between actual voluntary blinks and "false blinks" caused by room lighting, involuntary blinks, eye lashes, user fatigue and spasms. The BlinkSwitch is not adjustable and automatically calibrates itself to reduce the effort required on the part of the caregiver. The completed BlinkSwitch has finally made blink detection a viable communication option at a low cost.

## BACKGROUND

Some individuals afflicted with conditions such as ALS and Locked-in Syndrome have lost all voluntary motor skills except eye motion. The communication/control options available to these persons are Voluntary Blink Detection (VBD), Eye Motion Detection (EMD), and various Opto-Electroencephelographic Techniques (OET). Voluntary Blink Detection is typically used with "scanning" software to allow communication and environment control. While this method is slower than than the random access EMD or OET methods, it has always represented the least complex, most cost effective option. Many persons afflicted with these conditions are cared for in a home environment where the complexity and cost of such equipment must be minimized.

Though cost effective, the current generation of analog blink detectors have proven highly frustrating for both the user and the caregiver. User frustration is primarily due to the detectors inability to reliably detect voluntary blinks leading to both false positive and false negatives. Of the two, users are bothered most by false positives because they cause wrong commands to be executed. Caregivers have been equally frustrated because this equipment requires frequent adjustment of the "blink threshold" and because of the difficulty in physically aligning the sensor with respect to the eye.

## STATEMENT OF PROBLEM

The problem we addressed was how to create a cost effective VBD which would minimize false positives, be easy to setup and require little adjustment. We felt that if we could solve these problems, both users and caregivers would find the VBD to be a highly attractive solution for eye motion based communication and control.

The problem is further broken down as follows:

1) Determining the causes of unreliable blink detection and finding cost effective solutions to these problems.

2) Reducing the caregivers' burden in setting up and adjusting the device by:
   a. Reducing the time required for initial set-up
   b. Reducing subsequent adjustments during use

## APPROACH

The approach was A) to conduct experimental research to isolate the specific problems with the existing analog approach and to B) design a device which incorporates cost effective solutions to these problems.

A) Experimental Research into the causes of unreliable performance in analog blink detection systems isolated the following areas (in no particular order) which contributed towards false positives or false negatives in blink detection:

1) Detection Reliability Issues:

   a. Variations in the amplitude of the users' blinks.

   b. The effect of eyelashes which can intermittently reflect the infrared energy. This was most often manifested by "multiple activations" for a single blink.

   c. Variations in outside sources of infrared energy (e.g. sunlight, incandescent lighting)

2) Set-up Reliability Issues:

   a. Improper alignment of sensors with respect to the eye.

   b. Improper adjustment of "blink threshold".

   c. Improper adjustment of the time required for a blink to qualify as a voluntary blink.

B) Design Solutions to improve reliability were implemented by using a microprocessor to analyze and process the signal from the sensor. The same microprocessor provided a convenient method of assisting the caregiver in set-up and adjustment. The specific design solutions are presented below:

Solutions to Detection Reliability Issues

1a) A solution for amplitude variations consists of an algorithm which constantly updates the "blink threshold" based on the weighted average amplitude of previous blinks.

1b) A "hold off" algorithm was implemented to keep eyelashes from inadvertently reactivating the BlinkSwitch immediately after a valid voluntary blink.

1c) A pulsed infrared source is used for illumination of the eye by the sensor. The ambient IR radiation level is measured when the infrared source is off and then measured again when the infrared source is on. The ambient radiation level is then subtracted from the level when the infrared source is on, therefore nullifying the effect of ambient radiation.

Solutions to Set-up Reliability Issues

2a) The solution to the sensor alignment issues involves the following items: providing a "signal strength" lamp which shows the operator the level of reflected light; providing an infrared detector of adequate "field of view" to be tolerant of alignment errors while still being narrow enough to make the change in reflectance significant with respect to the background noise; and providing complete detailed instructions for the alignment procedure.

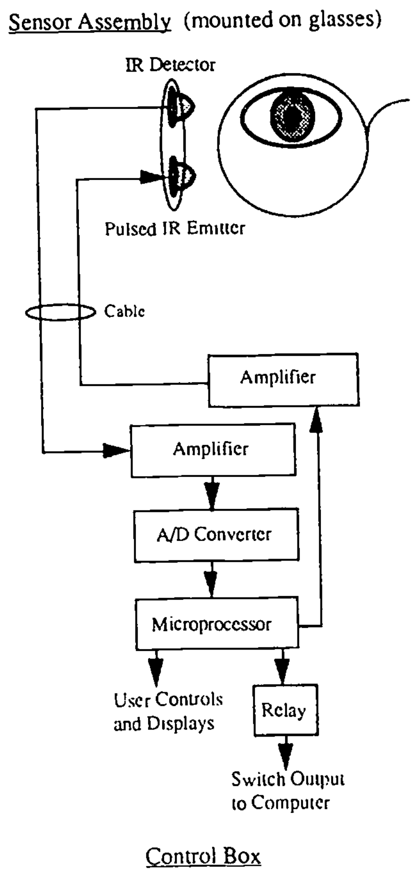
2b) Automatic calibration of the "blink threshold" based on the first blink with automatic "fine tuning" over subsequent blinks.

2c) A non-adjustable time period is used to differentiate between a voluntary and an involuntary blink.

## DESIGN & DEVELOPMENT

The design and development of BlinkSwitch was undertaken with a systems engineering methodology - in other words, all of the design features were assumed to be interactive. For example, our research indicated that improper system set-up by the caregivers was a significant factor in lowering the reliability of the device. Furthermore, that feedback was an important feature to help caregivers set-up properly. Our systems design approach therefore included a signal strength lamp to help the caregiver to properly align the eyeglass mounted sensor in addition to the processing the raw data from the sensor.

Figure 1 describes the BlinkSwitch system. The BlinkSwitch consists of a Sensor Assembly which is mounted onto the frames of eyeglasses (lenses can be removed for those with adequate uncorrected vision) which is connected via cable to a Control Box which contains the bulk of the electronics.




**Blinkswitch Block Diagram**
**Figure 1**

The Sensor Assembly consists of wavelength matched IR diode and IR detector with appropriate hardware for mounting and aiming these devices on the eyeglasses. The IR illumination is created by the IR diode which is pulsed under the control of the microprocessor. The IR energy reflected back to the IR detector is proportional to the degree that the eye is closed.

The Control Box Assembly analyzes the signals from the sensor assembly, handles user inputs and displays as well as providing the switched output when a Voluntary Blink is detected. The signal from the IR Detector in the Sensor Assembly is first amplified then digitized via the D/A converter so that numerical operations can be performed and so that the signal level can be "memorized" for use in the algorithms which determine that a blink has occurred. The Blink determination methodology is discussed in the approach section.

User-controls have been minimized to eliminate confusion. These controls consist of a power switch, a reset switch, and a bypass switch which simulates a blink for caregiver testing.

User-displays utilize different color lights to provide the users with maximum feedback (a key feature in increasing reliability). These displays include: a Power-on lamp; a "Signal Strength" lamp depicting the intensity of reflected IR from the sensor (for use during set-up); a lamp which illuminates each time that the unit appears to have detected a blink of any kind; and a lamp which lights when a voluntary blink has been confirmed.

The BlinkSwitch has been designed to meet the objectives of reliability and low cost while incorporating attractive packaging and ergonomic design features.

## EVALUATION

The BlinkSwitch is currently going into beta testing Early results have been extremely encouraging in showing that this approach may be almost an order of magnitude more accurate than conventional analog blink detectors. While the cost to produce this unit is somewhat greater than conventional units, it is expected that this cost will add no more than $75 to the eventual retail price.

## DISCUSSION

Blink detection has always been the most cost effective method for communication and environmental control for those individuals whose motor coordination is limited to eye/eyelid motion. It is hoped that the increased reliability and ease of set-up of BlinkSwitch will lead to increased acceptance of blink detection technology for those who can benefit from it.

## ACKNOWLEDGEMENTS

The work of Phil Malone, Bill Sachs and Bob Murphy in developing the Bl nkWriter and the later Blinkswitch systems is hereby acknowledged. These gentlemen performed the bulk of the research and development of this device as volunteers in Volunteers for Medical Engineering, Inc.(VME).

## ADDRESS

Mr. Jeffrey Jerome
VME Technologies, Inc.
5202 Westland Blvd.
Baltimore, MD 21227
(410) 455-6395

# The CHEC 2, Integrated Environmental Control System

Ed Snell, CET., Larry Silver and Chris Ridpath
Responsive Development Team
Bloorview Childrens Hospital
Willowdale, Ontario, CANADA.

## ABSTRACT

As more persons with severe and complex disabilities move into community based living situations, there are increasing demands on technology to facilitate independence with activities of daily living. Many technologies currently available are function specific, ie. a system to control the lights and a separate system to operate the telephone. Each system has its own access strategy and requires separate input switches and sites. The Computerized Home Environmental Control (CHEC 2) is an integrated environmental control system providing control of 256 devices operating from household current, 16 single switch functions, telephone control and 108 home entertainment functions through the use of only two user interface "switches". The same two switches allows the user to completely setup or modify the system configuration. Basic emergency functions are battery backed up in the event of a power failure.

## INTRODUCTION

Application of appropriate levels of technology in conjunction with attendant care support and more accessible housing allows many persons with disabilities to live independently in the community. Only a few years ago these persons would otherwise be confined to an institution and restricted from maximizing their potential. Limited availability of attendant care time requires persons with disabilities to utilize technology in the community to perform functions previously augmented by the helpful hands of institutional health care staff. However, many technologies developed to perform environmental control functions have focused on specific short term needs and have not addressed the more global needs of persons in independent living situations. Operating characteristics of each piece of technology are often unique and exhibit generally poor correspondence between visual-perceptual feedback and functions performed. Learning curves to develop proficiency with such technology are extended and are adversely affected by cognitive deficits. Accessing various functions through the same techniques and providing more personalized feedback greatly reduces learning/training time.

## BACKGROUND

The CHEC 1 firmware concept was developed in 1986, initially for the Muscular Dystrophy (MD) population, based upon the Commodore C64 personal computer. The complete system was operated through two interface "switches" selected and positioned for a particular individual's needs. The user switches allowed the user to scan and select functions presented in menus on a video monitor. Two prototypes were constructed; one still remains in use today. The system function was limited by the computer's small memory size and the fact that it primarily controlled existing technology designed for single switch access. If the power failed, someone had to reload the software by accessing the C64 keyboard. Field testing guided designers to incorporate many new features in the development of the CHEC 2.

## THE CHEC 2

### PHYSICAL DESCRIPTION

The CHEC 2 is housed in a non-obtrusive, table mount, 19" enclosure with an internal card cage. Function specific environmental control cards are inserted into the rear of the enclosure, forming the rear panel. A 3.5", 720K, disk drive is also mounted in the rear panel where the main program software and the user configuration information is stored. All connections to the CHEC 2 are made via the rear panel. The front panel contains two lighted pushbutton switches intended for casual control of the system while the switch illumination indicates the system is functioning correctly.

Accessories provided with the CHEC 2 include:

1) Monitor/Television
2) X-10, CP290 controller
3) Speakerphone
4) CSA/UL AC adaptor
5) PC-XT keyboard

THE VISUAL DISPLAY

A monochrome video monitor or a black and white television is used to display menu lists of labels which can be scanned and selected, with a highlighter bar, by the user input switches. The menu definitions are illustrated in Figure 1. Only three menu lists are supplied with the software, the MAIN, PHONE and UTILITIES lists. All other label lists are created and organized by the user to provide meaningful correlation to their personal applications. The additional user lists may be set up much like a software flowchart where one list may branch to another and so on. The user lists are stored on the 3.5" disk which is the only limitation to the number of lists created (no one has ever exceeded the disk capacity).

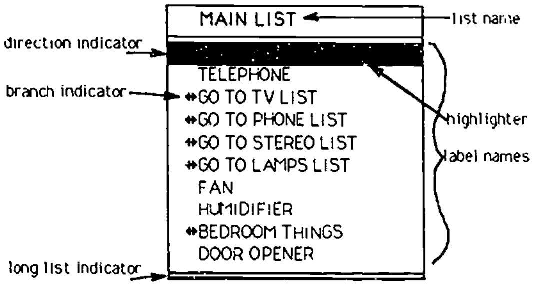



Figure 1: A typical CHEC 2 Menu.

The user input switches normally perform scan and select functions on the lists. When the user selects to create or modify a label on a list, the scan/select switches automatically become morse code switches to enter label characters. After the label characters have been created with morse code, a morse code "carriage return" signals the system to return the switches to the normal scan/select mode. A PC-XT compatible keyboard is supplied along with the system, allowing someone not familiar with morse code, to setup or modify lists of labels using standard keystrokes.

A screen saver routine has been built into the software that automatically switches off the menus when the user switches have not been activated for a period of time. This feature extends the life of the monitor. Any input switch activation returns the system to normal display.

FUNCTION SPECIFIC CARDS

X-10/Ultra-4/Single Switch

X-10 Homecontrols Inc. manufactures a wide range of remote control products for household power control including appliance, lamp, security and universal modules. The X-10 functions are controlled via the X-10 Model CP290 which provides the, CSA/UL approved, isolated connection between the CHEC 2 and home power lines. The hardware on this card communicates with the CP290 to identify which of the 255 possible X-10 modules to control and whether the desired function is ON, OFF or DIM (lamp modules only).

The Ultra-4 product line is marketed through Technical Aids and Systems for the Handicapped (TASH). These products are controlled through ultrasonic signals which are generated by the CHEC 2 hardware. All four frequencies are supported.

There are a wide variety of products from many manufacturers which are intended to be controlled from a single switch. Some examples might be personal tape recorders or transmitters for power door openers. The CHEC 2 provides 16 isolated single switch outputs.

Telephone

The CHEC 2 telephone board is intended to be used in conjunction with a commercial speakerphone. The telephone board provides Touch Tone and Pulse dialling, Direct Dialling, Last Number Redial, Call Waiting and Call Hold functions. The software allows the user to create a directory list of names (which is automatically alphabetically sorted) with the actual telephone numbers and personal information imbedded behind the name (much like a card file). Dialling is accomplished by merely selecting the name. Power for the speakerphone is supplied from a battery backup within the CHEC 2 described later in this paper.

Home Entertainment

Most modern home entertainment systems are available with infrared remote controls, but their operation is manufacturer dependent. Trainable infrared controls are available on the consumer market to reduce coffee table clutter of multiple infrared controllers. The CHEC 2 incorporates a 108 function trainable infrared control that has provisions for multiple infrared beacons. The 108 functions can be designated in any manner the user requires for their home entertainment configuration.

The CHEC 2

Power Supply

The external table top AC adaptor for the CHEC 2 has multiple safety approvals including CSA and UL. The input power requirements are 90 to 250 VAC, 50 - 60 Hz only requiring a cord set change to make it compatible around the world. The DC output connects to the CHEC 2 POWER card and supplies power to the various electronic circuits in the CHEC 2. The POWER card charges an internal backup gel battery and, during power failures, converts the battery energy to the appropriate operating voltages for the CHEC 2 including 9 volts DC for the external speakerphone.

## THE SOFTWARE

The software communicates with the various function cards over a parallel proprietary bus. The software allows the user to perform sequential unrelated functions from a single menu selection. A common desired function might be to MUTE the stereo or television when answering the telephone. The user creates a label for this called "ANSWER" and then is allowed to select any other labels, previously created, to be performed. This feature is called PICK EXISTING and the user would select ANSWER THE PHONE, MUTE STEREO, and MUTE TELEVISION. The CHEC 2 performs the new ANSWER label like a batch file.

The flexibility of the software design allows the user to create function names that are personally meaningful and facilitates rapid competency with the CHEC 2.

The software provides the user with utilities for adjusting the menu scanning rate (a number from 1 to 30) and the scan type (HOLD, STEP or AUTO). Another utility allows setting one or two switch morse code and the input rate for one switch morse code. Auditory feedback is provided during menu scanning and morse code entry which the user can adjust the volume level. Any function that the CHEC 2 has been setup to perform can be performed as a timed function. The TIMER utility allows the user to establish events to occur on a weekly 24 hour basis. These can be setup using the PICK EXISTING facility.

## EMERGENCY OPERATION

In the event of a power failure or a hardware malfunction, the CHEC 2 enters an emergency mode of operation. In this mode the two user input "switches" become specific function switches. One switch controls the telephone board to answer incoming calls or to dial the operator for assistance. The second switch now controls single switch output #1 for whatever the user may wish to activate. The internal backup battery will provide power for 24 hours.

## CONCLUSION

Two prototype CHEC 2 systems have been in existence for approximately three years. One system has been used in an independent living situation while the other unit has been used for testing and demonstration. There have been only minor problems which have been addressed. The CHEC design has been formalized and ten units constructed for local distribution.

The CHEC 2 represents a top end integrated environmental control system providing the user with a means to rapidly gain proficiency through personalized characterization. It is anticipated that the CHEC 2 will have a significant positive impact on the quality of life with independent community living.

## ACKNOWLEDGEMENT

The authors wish to thank the Bloorview Foundation for their continuing support of the Responsive Development Team.

For further information contact:

Mr Ed Snell, CET.,
Coordinator, Rehabilitation Technology,
Bloorview Childrens Hospital,
25 Buchan Ct.,
Willowdale, Ontario, M2J 4S9.
CANADA

P3.9

# ABLEAIDE©: FOSTERING SCIENCE AND TECHNOLOGY STUDIES THROUGH APPROPRIATE ASSISTIVE TECHNOLOGY

Randy W. Dipner, Daniel K. Davies, and Robert H. Gattis, Jr.
Meeting the Challenge, Inc.
Colorado Springs, CO 80907

## ABSTRACT

AbleAIDE is an expert system designed to encourage disabled students to take science and technology courses by matching assistive devices to the requirements of such courses. AbleAIDE assists a college counselor by proposing specific assistive devices or accommodations based upon an individual student's disability and the course task requirements.

## BACKGROUND

AbleAIDE forms the core of a research study investigating methods to encourage more disabled students to take science and technology classes and to consider a career in science or technology. This research study is being conducted as part of the National Science Foundation's ACCESS Project.

## STATEMENT OF THE PROBLEM

Disabled students have been traditionally under-represented in science and technology professions. AbleAIDE is an attempt to make it easier for a disabled student to succeed in a science or technology course by explicitly defining the course task requirements and finding appropriate assistive devices to allow the student to meet these requirements. The AbleAIDE concept is shown in Figure 1.

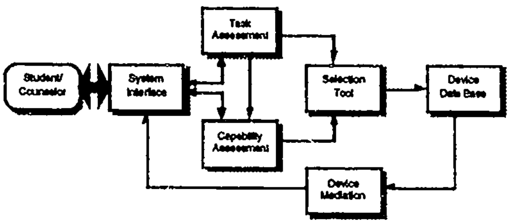



Figure 1

## APPROACH

There are a fair number of on-going projects that involve expert systems or decision aids applied to disability issues. Further, references throughout the literature indicate that this is an area for fruitful research. For example, in the *Assistive Technology Sourcebook*, Kathy Lee is quoted (1): "When only a few options [assistive devices] existed, a trial and error method or trying on of access systems was feasible and not impractical. With a proliferation of access systems, it is now necessary to systematically and objectively consider options to determine which will best satisfy the user's needs and abilities." Unfortunately, most of the projects currently under devcopment that are related to device selection have a very narrow perspective.

It appears that all of the device selection systems under development or currently available were forced to focus on a very narrow segment of disabilities, tasks to support, and/or assistive devices because they attempted to make a very specific recommendation. It seems possible that by keeping the prescriptive activity at a more general level, the expert system might become manageable across a wider spectrum. While this would not provide a replacement for the professional therapist, it could significantly enhance the ability of either a professional or non-professional to locate a group of devices that could then be considered using good old common sense. The final selection should be left in the hands of the disabled individual and the counselor anyway.

A critical problem in the use of an expert system for device selection is the type of data available in on-line databases of assistive technology. While there are large numbers of devices indexed, the amount and types of data available for each device is, in general, insufficient to make a selection.

### *Databases*

There are many assistive device databases currently available which could form the basis for the device database segment of AbleAIDE. ABLEDATA and its Hypercard implementation, HyperABLEDATA, contain the largest number of devices. This fact led us to use ABLEDATA as the starting point for the AbleAIDE application.

The key deficit in all known device databases is the lack of quantified, specific attributes for each product that would allow direct selection of the single best product for a particular application. In general, databases contain an abbreviated description extracted from the manufacturer's sales material. No verification of performance to these specifications is provided. George Kondraske (2) suggests that buying assistive technology without quantitative performance data is like "purchasing clothing from a catalog without size information." This analogy can be extended to show that complete quantitative information is not always required. For example, some clothing items such as handkerchiefs do not require quantitative size information for success. Also in some cases only a subset of quantitative information is pertinent. For example, shoe size is irrelevant to buying a shirt. Even in light of these latter examples, a significant enrichment of existing databases in terms of quantitative data or attributes is necessary.

### *AbleAIDE design concept*

The most important aspect of the AbleAIDE design seems to be the *consistency* of the attributes used in the task assessment, the capability assessment, and the device database. In this section, we present a basic concept for a system that takes advantage of many of the existing systems.

***Task and capability assessment concept.*** In general, the task and capability assessments will be conducted by asking a series of questions to which the counselor and student will respond. These questions will be tailored to the particular class or curriculum desired, rather than to the more general totality of life's functions or student's capabilities. The rationale for this limitation is depicted in Figure 2. As shown, the capabilities required to succeed in a college course are a subset of the total individual capabilities required for life. Many of these life-function capabilities may also be outside the individual's personal capabilities. Some may be necessary for the individual to live independently or gain employment but are not required for his/her education. The most important portion of the capability space is that segment required for the specific class or curriculum under consideration that is *outside* the individual's capability space (as depicted by the shaded portion shown in the figure). Thus, the goal of the assessment activity must be to determine the content of this shaded area.

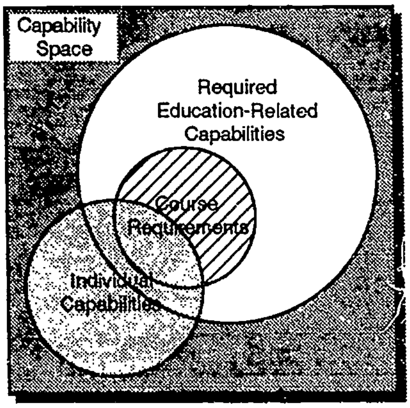



Figure 2

Based on this concept, it is proposed that the initial step of the assessment be the task (class or curriculum) assessment. This assessment could be performed off-line from the student counselor session. Alternatively, the capability might be present to develop the task assessment during the student/counselor session. Only high enrollment courses might be developed off-line, with less frequently offered courses developed as required. Once developed, the capability should be provided to store the developed course assessment for future use. In this way, the catalog or database of task descriptions would evolve over time.

In general, the questioning would address skills by categories. For example, general education skills, such as reading a textbook, listening to lectures, taking notes, taking tests, doing homework, or asking questions in class would constitute one category. A second category would be devoted to capabilities required for a particular course. These might include using a computer or working in a chemistry lab. The response method might be patterned after the OT Fact model, with the answer to each category or subcategory question being one of: *total, partial*, or *no requirement* for the particular skill. No additional questioning would be required for a total or no requirement response. The *no requirement* response would imply that the student would not be required to perform any of the category actions. A *partial* capability response would produce a more detailed level of questions. For example, if the task/course required only *partial* use of the computer, it would be important to know if:

1) using a keyboard, a mouse or other manipulative device is required, or
2) whether seeing the screen is required, etc.

It may be necessary to display the functional content of a category to allow the counselor to make a reasonable assessment of the *total, partial* or *no capability* requirement at a given level.

The capability assessment for a particular student would follow a path parallel to the course requirement assessment. That is, the question categories for the capability assessment would be consistent with the course requirement assessment. The system will only display those categories required for the particular course. For example, computer-use questions would not be presented if computer use was not prescribed in the task assessment. It is assumed that a student profile based on total education capability or at least general education capability requirements could be made once and stored. Using this stored profile, the number of questions could be further reduced. As the student takes more courses and the profile becomes more developed, the questions for a new course would be further reduced. There may be a need for a curriculum-level assessment to allow a high level assessment to be performed before a student starts down a path that might eventually have an insurmountable capability requirement. Even if the decision was to proceed down the apparently impossible path, the counselor and student would have an early awareness of the future needs that would be the most difficult to meet. For example, if special equipment would have to be fabricated for a particular course, sufficient lead time might be gained through this mechanism.

***Database attribute concept.*** The database design must be attribute rich. The attributes must parallel those contained in the task and capability assessments. That is, it does no good to determine that certain capabilities are required for performance of a given course and then to not be able to search the database on those same attributes. Even with a rich, consistent attribute set there may be complications to overcome.

The AbleAIDE database needs to be structured so that any product can be allocated as many attributes as exist. This approach is similar to that employed in the Closing The Gap database of assistive devices. The design starts with some attribute categories to aid in the design and the organization of information; however, these categories are not restrictive. That is, a database entry or product can have multiple attributes within any category. Thus, a product could, theoretically, have every attribute contained in the database. The goal of this approach is to allow products that might normally be viewed as products for a particular disability to match the requirements for a different disability or use than generally considered. This richness would be a significant benefit for the user of the system.

It may be valuable to include non-product accommodation techniques in the database. This is particularly true where a capability is required for certain courses which is not currently met by any product but could be met by some alternative teaching approach or other accommodation. For example, a tutor or interpreter might be the optimal solution for a given task, rather than any technological device.

## DISCUSSION

Given the definition of the two major components of the AbleAIDE system described above, it seems appropriate to present an overview of the proposed process flow. Figure 3 pictorially describes the process flow.

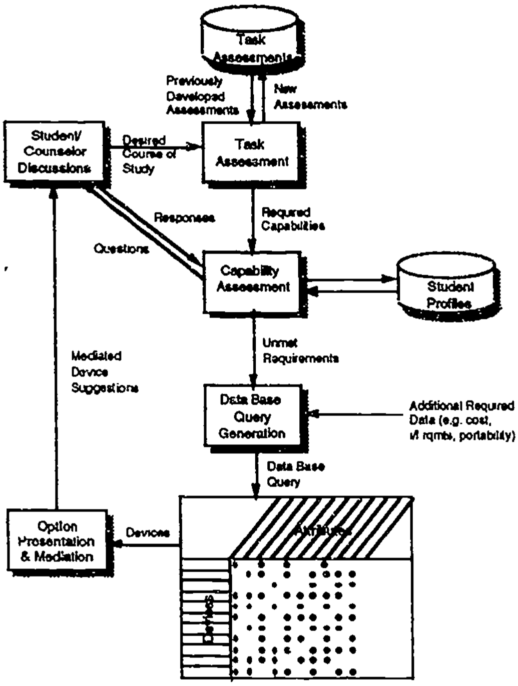



Figure 3

The process begins with the student and counselor discussing and arriving at a proposed course of study or a single course. The system is entered with a request for information on that course of study. If a task profile has been previously entered, the system would retrieve it. Otherwise, the counselor is prompted to enter the necessary descriptive data on the course and that description is archived.

The required capabilities for the course are passed to the capability assessment portion of the program. If the student's profile or partial profile has been previously entered, the system retrieves it and uses it to make an initial assessment of student capability for the course. Note that the profile could include capability provided by previously acquired assistive technology. If no student profile exists or the profile is inadequate for the particular task being evaluated, the system will prompt the counselor and student for additional data to complete the profile as needed for the task under consideration. It is not intended that the complete profile of the student be entered in this real-time setting. A possible off-line student profile entry capability might be of value.

Once the student capabilities are available, they are compared to the task requirements. The deficits in this comparison are the requirements that must be met by some means other than the student's current capabilities. If no deficits exist for the particular course, then no additional assistive technology or accommodation is needed for the student to attempt the course. Some additional data may be necessary at this point if deficits do exist. In particular, data such as the available dollars or the interface requirements to existing student-owned assistive technology, would be required. These data would be incorporated with the task deficit data and used to search the database for a product, products, or other accommodation technique that could allow the student to successfully attempt the course.

The results of the database search would be presented to the student and counselor along with the results of the overall assessment and search process. The presentation would be in the form of alternatives, rather than a single "right answer." It is left for the counselor and student to make final decisions concerning which alternative to follow or perhaps to conclude that all alternatives are infeasible or undesirable. The presentation of products should at least present or highlight differences among the products presented. That is, some form of product strength and weakness profile for the particular application should be available to the student and counselor for their decision process.

It is possible to visualize a system which works with the student and counselor to determine which of several options is best by asking for additional information. This process would aid in comparing one product to another and eliminating those devices that do not satisfy the student.

A prototype of the AbleAIDE system is currently being built to test the thesis that the provision of appropriate assistive devices will encourage disabled students to pursue courses and careers in science and technology.

## Acknowledgements

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Robert H. Gattis, Jr.
Meeting The Challenge, Inc.
3630 Sinton Rd., Suite 103
Colorado Springs, CO 80907

# Research on Personal Interface and Development of Input/output Devices for the Disabled

Seiji Kitakaze
Kansai C&C Research Laboratory
NEC Corporation
Chuo-ku, Osaka, JAPAN

Abstract

A user interface design method, which considers the user's physical characteristics and utilization features, was discussed. An input device for the physically handicapped and an input/output device for the visually handicapped, with appropriate design were developed.

Development of personal computer input/output devices for the handicapped is very significant, because the devices allow them to make sentences or obtain some information while using the devices. However, development is very difficult, because every handicapped person has his or her own handicap part and level, so a device, which has a fixed interface, cannot cover many users' needs. Therefore, high adaptability is demanded to make an appropriate user interface for them.

This highly adaptable user interface is called a "Personal Interface". The design method was proposed, considering the users' physical characteristics and utilization features. Further, the method was adapted to devices designed for both the physically and visually handicapped, who encounter great difficulty in using an ordinary personal computer, and the "Soft Keyboard" and "Braille Partner" were developed.

## 1. Introduction

Much information can be obtained and sent using a personal computer (PC), creating a meaningful life, owing to expansion of information processing techniques. The physically or visually handicapped, however, find difficulty in obtaining these benefits, because they find it very hard to use the keyboard and see the display. If they were able to use a PC very easily, they could make sentences and express their thoughts, even if they cannot talk. They can obtain much information using a PC network, even if they cannot go out. These actions expand the worth of their life and allow them to study or work [1].

In Japan, MITI(Ministry of International Trade and Industry) presented guidelines for accessibility to information processing equipment in June 1990 [2]. The guidelines describe 4 kinds of aid, (1)keyboard, (2)display, (3)document and (4)supporting facilities, to allow using these equipments easily. Research on interface design and input/output device development in this field are foreseen to be very useful.

## 2. Concept for developing better devices

The main concept in developing input/output devices with suitable interface for handicapped persons is to design a highly adaptable interface. Every handicapped person has his own handicapped part and level, so a fixed interface places limits on the user. Moreover, some handicapped persons can change their handicap level.

Another concept is to design an interface to fit every use. If a PC has many software programs and many usages, it would be effective to use an adapted interface.

## 3. Personal Interface design method

The following discusses making the highly adaptable interface, called "Personal Interface", considering the user's individual physical characteristics and utilization features [3].

### 3.1. Analysis of the user's physical characteristics

This analysis was made to enable classifying the users' actions and movement capacity levels, as well as to obtain a suitable interface at each level. Designing the "Personal Interface" was implemented to obtain an adaptable interface, which can select and set every interface easily.

For example, a user's key stroke ability level can be classified from their hand action, according to whether they can use finger, hand, and other points of their body. Then, a key input method or key size for the keyboard can be decided which can adapt to each physical movementability level. Further, the "Personal Interface" can be designed using these analysis results.

### 3.2. Utilization features analysis

This analysis was made to classify the software use, and to obtain a suitable interface on each level. Designing the "Personal Interface" was implemented to achieve an adaptive interface which can also select and set every interface easily.

For example, usage can be classified, like reading a newspaper or word selection from a dictionary. Then, reading and selection functions are designed as an interface. Further, the "Personal Interface" can be designed using these analysis results.

## 4. "Personal Interface" design for handicapped

An interface was designed for the upper limb and the visually handicapped, using the "Personal Interface" design method.

### 4.1. Interface design for the upper limb handicapped

It is necessary to design an interface into which data or instructions can be easily input, because the handicapped find it difficult to or cannot strike keys on a keyboard.

In an analysis on the users' physical characteristics, the person's key stroke action level capability must be classified. An analysis of the handicapped persons ability level, number of controllable keys and a suitable interface are shown in Table 1. If a person can use his fingers, he can strike a little bigger key, so an interface which strikes keys directly is suitable. If a person can strike two more keys, using his fist, an interface is suitable which can be used to strike some keys to select the letter he wants input. If a person cannot use his hand, but can control one switch, using his breath or by winking his eye etc., an interface is suitable, which inputs when scanning the letter he wants to input. "Personal Interface" is to get adaptive interface which can select and set individual interfaces easily.

In features utilization analysis involves classifying software use. An analysis of usage, software and a suitable interface is shown in Table 2. The main usage to allow the handicapped to communicate by making some sentences. In this case, the user can handle the word process function, so the function which can easily select and choose a Hiragana (combined consonant and vowel Japanese character) key. In the case of using math education, a good interface must be able to input a number easily. "Personal Interface" is obtain an adaptive interface, which can be used to select and set individual interfaces easily.

### 4.2. Interface design for visually handicapped

A device, which can be used to input data very easily, because of the difficulty in making a key decision, and can read text on the display, using some other method, is effective for the visually handicapped.

In analysis of users' physical characteristics, it is possible to classify handicap level and Braille usage level. Handicap level, braille usage level and a suitable interface are shown in Table 3. For a person who can hardly see, an interface using voice or enlarged text is suitable. For a person who cannot see and does not know Braille, an interface using voice is suitable. A person who know Braille can use Braille input/output interface and voice output interface. "Personal Interface" is to obtain an adaptive interface, which can select and set every interface easily.

In utilization features analysis, the usage contents can be classified. Usage and a suitable interface are shown in Table 4. Their major uses are reading and making sentences, selecting a word in a dictionary and exchanging information using PC communication. Therefore, reading and word processing functions, looking up a word function using CD-ROM, and PC communication function are designed as an interface. The "Personal Interface" is to obtain an adaptive interface, which can use every function easily.

## 5. Development of devices for handicapped

The authors developed an input device, "Soft Keyboard" for the upper limb handicapped, and an input/output device, "Braille Partner", for the visually handicapped, using a "Personal Interface" design method.

### 5.1. Soft Keyboard (Flexible Keyboard)

A "Soft Keyboard" was designed to improve accessibility for people with upper limb handicap [4]. The "Soft Keyboard" consists of a touch sensitive display, touch panel, some switches, like a breath switch, and appropriate software. The touch sensitive display, with touch panel and switches, functions as a keyboard and operates under the control of software, as shown in Fig.1. Key size, position, content and activating pressure are determined by software programs. Key input is carried out in three different ways, (1)touching the key on the display directly, (2)moving the cursor, using a touch panel, to assign the desired character and (3)pressing the input key, using some switches while the characters are scanned sequentially. Further, editing software, which can design key size, position and content, is also provided to support user customization.

### 5.2. Braille Partner (Braille Personal Computer)

A "Braille Partner" was developed to support the visually handicapped [5]. It consists of a Braille keyboard, a Braille pin display, a text to speech synthesizer and control software attached to the NEC "PC-9801" personal computer, as shown in Fig.2. The Braille keys layout was determined under

Table 1. An analysis on the users' physical characteristics for upper limbs handicapped

| level | keys | interface |
|---|---|---|
| fingers | more than 10 | directstrike |
| fist | 2 - 9 | select input key |
| other points | one | scan and input |

Table 2. Features utilization analysis for upper limbs handicapped

| usage | software | interface |
|---|---|---|
| communication | word process | Hiragana keys |
| education | math, science... | number keys... |
| business | accounting... | number keys... |

Table 3. An analysis on the users' physical characteristics for visually handicapped

| | | interface | |
|---|---|---|---|
| level | Braille | input | output |
| hardly see | | | enlarged text |
| blind | unknown | | voice |
| | understand | braille keyboard | pin display<br>voice |

Table 4. Features utilization analysis for visually handicapped

| usage | interface |
|---|---|
| reading and making sentences | reading and word processing |
| selecting a word in a dictionary | looking up a word in CD-ROM |
| exchanging information | personal computer communication |

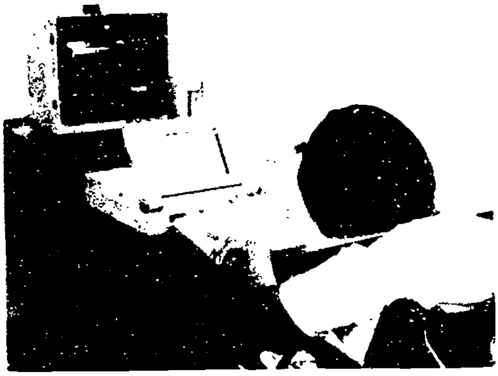

Fig.1. Soft Keyboard (Flexible Keyboard)

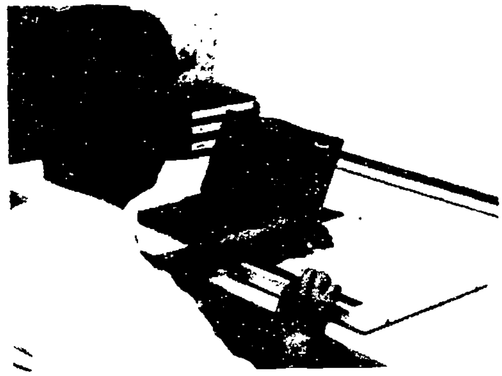

Fig.2. Braille Partner (Braille Personal Computer)

guidance from the input/output systems development committee, specially organized for the visually handicapped. The Braille pin display can display 40 characters at a time, which correspond to a row on the screen. The text to speech synthesizer generates sound from text, including Kanji (Chinese ideographs) characters, which have several different pronunciations, where each Kanji character can be pronounced differently, depending on the context. These functions are utilized for confirming the key input, as well as for reading the text on the screen. The total software, with reading and word processing, looking up a word in the CD-ROM dictionary and connecting PC communication network, was also developed.

## 6. Evaluation of input/output devices

The authors are now evaluating "Soft Keyboard" and "Braille Partner" in special education school, rehabilitation center and welfare center. Many handicapped persons use these devices directly, and are evaluating usability.

They are using "Soft Keyboard" to make sentences for human communication and to study using education software. They consider it is very effective. There are also some requests to miniaturize and make it portable and to settle a voice function, which speaks what they input. They are also using "Braille Partner", which connects a PC network to get some information, like news, and to communicate with some other member. This is very effective, too. There are also some requests to simplify its operation.

## 7. Discussion

It is important that the personal computer input/output device, which can be easily used by the handicapped, can be used by many persons and for many uses. The authors proposed "Personal Interface" design method considering the users' physical characteristics and utilization features. Further, the interface was adapted for the physically and visually handicapped, who have great difficulty in using a computer. The authors developed "Soft Keyboard" and "Braille Partner".

A further approach to "Soft Keyboard" is to collect data regarding suitable key size, position and content, and to consult with appropriate personnel to easily obtain a suitable interface. Further approaches to "Braille Partner" is the ability to use Kanji Braille, and to make some functions to use many software programs for them. "Personal Interface" design method is also use to develop new devices for the handicapped, and its use was started in other fields, like for aged persons and patients in a hospital.

## Acknowledgements

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Seiji Kitakaze
Kansai C&C Research Laboratory
NEC Corporation
4-24, Shiromi 1-chome,
Chuo-ku, Osaka-shi, Osaka 540, JAPAN

P3.11

# CONDITIONS FOR FULL ACCESS TO THE GRAPHICAL USER INTERFACE: TECHNICAL SOLUTIONS AND AVAILABILITY

Lawrence Boyd, Wes Boyd, Joseph Robinson, Marc Sutton, Jane Berliss
Berkeley Systems, Inc., Berkeley, California

## INTRODUCTION

Forces of revolutionary significance in computer technology were loosed by the development of the graphical user interface (GUI). GUI is easily distinguished by the extensive use of object metaphors (icons, windows, and other visual control techniques), the prolific use of graphics to convey information, and the use of a mouse for cursor pointing and control. Ironically, even as the new interface provided new power and ease of use to sighted people, its technical differences and increased dependence on visual metaphors virtually obliterated existing computer access technology for blind people (3).

To avert the seemingly inevitable disaster, two things had to happen. The technical problems of accessing the GUI first had to be solved; the solutions then had to be made available and adaptable. This paper describes how these two issues are being addressed.

## THE FIRST CONDITION FOR EQUAL ACCESS: TECHNOLOGICAL SOLUTIONS

What was immediately intuitive to many people has been confirmed by scientific research: for sighted users, the GUI is easier to learn, speeds up communication with the computer, and enables more professional-looking and attractive presentations (8, 9). Graphics-based operating systems are now being developed by all major manufacturers and are emerging on increasing scales in employment, education, and community settings (4, 7).

Unfortunately, these systems initially had inherent obstacles for blind users. Technical solutions to this access problem faced three formidable barriers: the use of pixels instead of a text buffer, the reliance on graphics to convey information, and the use of the "mouse" cursor control device.

### Accessing text through the off-screen model

Unlike earlier computers, graphics-based computers do not have a text buffer for storing characters and displaying them on the computer screen. Instead, the representation of the screen in memory is made up of pixels (dots). Both text and pictures are displayed in the same way. A program sets the appropriate pattern of dots in memory, and this pattern is then "painted" onto the screen as clusters of selectively darkened pixels. The problem for conventional screen access software programs is that they depend on the presence of a text buffer, and cannot interpret clusters of pixels appearing on the screen.

The strategy that finally cracked the pixel barrier "grabs" text information before it gets to the screen. The information is intercepted and stored in a special database before it is displayed on the monitor. This database (now known as the "off-screen model" or OSM) is used to provide screen access (7). The first commercial application of this "interception approach" was outSPOKEN™ for the Apple Macintosh (2).

### Accessing objects through icon recognition

Perhaps the most troublesome problem for accessing the graphical user interface is the form in which information appears on the screen. Instead of using a highly specialized command language, the GUI represents information as objects or visual images that are meant to emulate common experiences (e.g., the user "drags" a picture of an unwanted file into the "trash" to dispose it). The problem for conventional screen reader technology is that it cannot interpret these metaphors. In particular, it cannot make sense of icons, style changes in text (for example, highlighting), and GUI structures such as pull down menus, dialog boxes, and scroll bars.

Fortunately, it is not necessary for a blind person to perceive the shape of icons to use them. All that the blind person needs to know is the fact that the pointer is over an icon. Interception-based software such as outSPOKEN is designed to recognize these icons. The software then "speaks" the text associated with that icon (which can be defined by the user). Likewise, interception-based software recognizes and tracks stylistic information about the text itself—the name and size of the font, the presence of formatting styles such as boldface or underlining, whether the text is highlighted, and so forth. The software also recognizes and tracks information about windows, menus, dialog boxes, control buttons, and scroll bars. Information such as type, status, size, location, and content of these standard graphical structures is also stored in the database.

### Accessing cursor movement through the keypad

In the GUI, a mouse is moved in a particular direction and a pointer moves in the corresponding direction on screen. To select an object or command, the user simply points to the object (using the mouse-controlled pointer) and clicks the mouse button. This process depends on eye-hand coordination and, therefore, needs to be executed differently by a person who is blind. outSPOKEN substitutes the manual functions of the mouse with keystrokes on the numeric keypad. With the numeric keypad, the blind user can perform standard control functions of the mouse. This includes reviewing the desktop, selecting commands from menus, activating windows, moving the pointer on the screen, selecting and moving objects, launching applications, reviewing, writing, and editing text.

## THE SECOND CONDITION FOR EQUAL ACCESS: TECHNOLOGY SHARING

A technical solution to a technological problem, no matter how serious and widespread the problem, and no matter how elegant the solution, is not sufficient if it does not spread throughout the industry through universal and easy access by all developers and end-users. As more GUI-based operating systems are developed and marketed, rapid diffusion becomes increasingly imperative.

To provide this condition, a modular, cross-platform development kit called GUI Access™ is being developed (5). This toolkit is designed for use by any developer or end-user who seeks to explore new access strategies and develop new software for people who are blind.

At the core of GUI Access is the technology developed for outSPOKEN described above which intercepts screen display calls and stores information in a database for later retrieval. This Off-Screen Model (OSM) includes the database and some machine dependent routines. Machine dependent information will be provided for Microsoft Windows and the Macintosh. By design, the machine specific portion of the module will be small enough that developers will be able to port to other platforms with minimal effort.

Sample input and output drivers will be included with GUI Access. These drivers are expected to have significant implications for exploring new ways of providing access to GUI-based systems. For example, GUI Access technology is being used in a project called Systems X (also known as Systems 3). The prototype consists of a mouse-like "puck" with an Optacon refreshable display mounted on the top, plus a haptic, absolute-position graphics tablet. When the hardware is connected to a Macintosh, it is used with speech output and tactile output drivers to permit access to graphic and combination text/graphic information, such as bar graphs. The user is able to explore the graph by moving the puck on the tablet and feeling graphic information. Textual information is spoken aloud as it is encountered.

## CONCLUSION

Many blind people still harbor the illusion that their decision to use or not use the GUI is somehow optional and that they need not be concerned about it. Staying with old access technologies may seem comfortable because the systems to which they provide access are still around. However, there is virtually universal agreement that those systems will not remain a standard for very long. Fortunately, as new technical problems emerge and are solved, and as new technologies are made available through enlightened technology sharing, the resulting computer access systems will provide persons who are blind with capabilities that were inconceivable with earlier systems (1, 9). As these realities sink in, the remaining hindrances to unprecedented levels of computer power for blind people, which are primarily psychological and social, will be removed.

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Lawrence Boyd
Berkeley Systems, Inc.
2095 Rose St.
Berkeley, CA 94709

# International Symposium

# on

# Robotic Manipulators in Rehabilitation Practice

# ROBOTIC MANIPULATORS IN REHABILITATION PRACTICE
# AN INTERNATIONAL SYMPOSIUM
## FOREWORD

Robotic manipulators have been applied very effectively in the industrial sector for decades now. They are being used routinely in the automotive industry to weld and paint cars and have proven very useful in harsh environments such as the nuclear or mining industries. But imagine using a mechanical arm as an assistant to individuals with disabilities. This hard, intimidating machine now becomes a companion, which will always be at your beckon call and will under no circumstances harm you. This is a tall order for any organization to achieve. In shifting the focus of robotics from the industrial sector to the service sector, the rules of safety, reliability, accuracy, and aesthetics, to name a few, have changed.

The idea of applying robotics to the service sector has existed in theory for some time now; however, only during the past ten years have actual robotic systems begun to emerge as assists to individuals with disabilities. A number of organizations have demonstrated the feasibility of using advanced technology to develop assistants in the home and office. The following pages represent the accomplishments in rehabilitation robotics of 11 distinguished organizations from around the world. As with any new technology, it will take some time before robotic assistants will be fully accepted; however, education is one key to acceptance.

This International Symposium is a leap forward in educating the end users and prescribers in available rehabilitation robotics technology. The systems described in the following pages have been and are currently being field tested and many of the systems are commercially available. I hope you will concur that this International Symposium was an effective tool in keeping you, the end user and prescriber, abreast of current technological advances in rehabilitation robotics.

I would like to express my appreciation to Geb Verburg from the Hugh MacMillan Rehabilitation Centre in Toronto for organizing this International Symposium. I would also like to thank all the presenters for their willingness to participate and for their prompt reply in submitting papers for inclusion in the proceedings.

Michael F. Burrow
Chairman, Robotics Special Interest Group

This symposium was organized to show rehabilitation professionals and potential users / consumers of this technology the most up-to-date examples of rehabilitation robotics and to share what these commercially available systems can do in real life situations.

Presenters from six countries, will share research results and information about seven robotic manipulator systems and applications of these systems in Independent Living and Vocational environments. The three sessions of this symposium each address a specific topic area within this general plan. Opportunities for Hands-On experiences will be available in the Thursday sessions.

Wednesday afternoon: **User Interfaces**
This session presents: an overview of European R&D projects toward an integral control system (van Woerden); Robotic User Interface (RUI) research efforts taking place at Stanford University (Leifer); user interface adaptations of MANUS (Kwee); and a new palatial interface developed by InventAid (Hennequin).

Thursday am: **Independent Living**
Three very different types of manipulators and evaluations of each of these are presented in this session: HANDY I, a Robotic Feeding Aid (Whittaker); REGENESIS, a workstation robotic assistive device developed by the Neil Squire Foundation (Birch and Fengler); and MANUS, a wheelchair mounted manipulator (Øderude, Brelivet/Thibault, Verburg et al.).

Thursday pm: **Vocational Applications**
Four presentations about three different manipulator types will share results of workplace applications: DEVAR, the system developed at the Veteran's Administration facilities in Palo Alto (Vander Loos, Leifer); the MASTER system developed by staff of the French Atomic Energy Commission (Détriché and Lesigne); UMI/RTX, an industrial system that has been adapted to the rehabilitation environment (Jackson et al., van Dort).

Geb Verburg
Symposium Chair

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# INTEGRATED CONTROL OF MOBILITY, MANIPULATION, COMMUNICATION AND THE ENVIRONMENT

J.A. van Woerden, J.C. Rosier
Institute of Applied Physics
The Netherlands

**Abstract**

Integrated Control Systems allow disabled and elderly people access to multiple functions from a single input device (for example a joystick with a switch). Multiply handicapped users are thereby able to switch efficiently between wheelchair control, manipulator control, control of their environment, computer access and communication without help.

This integrated system approach is part of two projects in the so-called European Community Programmes: one in the TIDE (Technology Initiative for Disabled and Elderly People) programme and one in SPRINT (Innovation and Technology transfer).

The TIDE M3S project (Multiple-Master Multiple-Slave) aims to become a general purpose interface for the Rehab world, while in the SPRINT project SP53 IMMEDIATE (Integrated System for Mobility and Manipulation for Disabled people) more emphasis is given to integrated control aspects.

**Introduction**

Many technical aids are available for the purpose of increasing the independence of severely physically disabled people. An increased independence (autonomy) of this group would have a positive effect on nearly every aspect of the lives of the disabled persons, e.g. on his or her personal activities and on vocational activities. For this purpose, top rate technology is employed to an ever increasing extent. Such technical aids are, for example, electrically driven wheelchairs, robot arms, remote control equipment etc. This large range of technical aids can be classified into five categories, namely technical aids for:

- mobility
- manipulation
- environmental control
- communication
- computer access

A wide range of companies and institutes develop these technical aids which offer the disabled the opportunity of functioning in a more independent manner with regard to these categories. However, until now the technical aids were developed in an uncoordinated way, resulting in a number of products not compatible with each other. In order to form a set of functions necessary for the independence, the disabled person is forced to buy a number of products each with its own user interface and possibly overlapping functionality.

The innovation of these EEC projects consists in the integral approach and the global analysis of systems. The projects will emerge on different compatible subsystems, which can be arranged in conjunction with the design applications.

**M3S project synopsis**

In the field of technology for the elderly and disabled people one can make a division between input devices and end-effectors. Examples of input devices are joysticks, switches, voice control, etc. Electrical wheelchairs, manipulators, environmental controllers could be considered as end-effectors. In aids for the elderly and disabled people one of both types of devices is incorporated. The input devices in fact determine for which kind of user group the aids are suitable. As in many aids one input device is integrated in the system, these systems can only be used by a limited user group. The M3S Multiple-Master-Multiple-Slave intelligent interface is meant to solve this problem.

In the M3S system different types of input devices can interface to different types of end-effectors. As this interface will be well specified, manufacturers of input and end-effector devices can adapt their devices to meet these specifications which ensures compatibility in the field.
The intelligence in the system is added to allow the interface to be optimally configured to the user needs. The intelligence in the system comprises of two parts:

- high level task execution
- signal processing functions

To perform the high level task the interface will be equipped to generate a sequence of output signals starting by a simple command of the user. This will enable the user to perform complicated tasks with little burden. The signal processing function ensures that the interface can be optimally configured to the needs of the user.
The Multiple-Master-Multiple-Slave concept has the advantage over many structures now used in the field that information can be send back to the user e.g. on the system status. The M3S architecture also facilitates the connection of different user interfaces to the network on different places in the system. In this way disabled and non-disabled people can have access to different parts of the system such as a television or a VHS.

After the functional specification of the interface and the analysis of the devices that will be interfaced by the M3S system, existing bus standards (draft ISO 7176, CAN, D2B, etc.) will be evaluated for their use as M3S bus. Based on these analysis the M3S interface, including the M3S bus, will be specified. As the M3S specification deals with the interfacing of most commonly used input devices and end-effectors it can be used for future standardisation Extending the use of the interface and formalizing it in a standard could be a TIDE main phase project.
The interface will be implemented in two demonstration platforms:

1. A system with a PERMOBIL wheelchair, a MANUS manipulator, a JAMES-like environmental control system, which can be controlled by a Penny and Giles joystick and a headrest sensor, a head pointing device and a tongue switch.

2. A system with a SKWIRREL wheelchair of Huka, a MANUS manipulator, a JAMES-like environmental control system, which can be controlled by a Penny and Giles joystick and a headrest sensor, a head pointing device and a tongue switch.

The interface implemented on these platform won't have the total functionality as specified for the M3S interface but only the subset that is needed to control the end-effectors with the input devices connected. The two demonstration platforms will be tested on technical performance and safety and evaluated on functionality in a limited number of user trials.

The major deliverable of the M3S project will be a thoroughly prepared M3S interface specification, demonstrated and evaluated in two platforms, starting point for future standardisation.

**Immediate Project Synopsis**

This project aims at the development of integral systems to assist disabled persons in their manipulation, communication and mobility. It is constituted by an electric wheelchair including assistance for driving, a built-in manipulator arm and an on-board environmental control system as well as assistive communication devices.
The electric wheelchair will most probable have semi-automatic functions such as the possibility to follow marks on the floor and/or localization of its position in a near natural environment. The manipulator and the wheelchair will be piloted in direct or automatic modes under the permanent supervision of the disabled user. The manipulator will allow the performance of automatic handling and grasping tasks of daily life.

The environmental control system will be controlled either by the user or directly by the system during the task. The operator interface will be configurable and adaptable in conjunction with the nature of the handicap.

The technologies concerned belong, on one hand, to the service robotics for definition of the mechanical structure of the arm and corresponding control command systems, for setting the sensors involved in safety, guiding and retrieving trajectories for the arm and the mobile base, and or the operator interfaces; and on the other hand, to commercially available technical aids for people with disabilities such as the electric wheelchair and environmental control systems.

At the laboratory level, some robotized systems for helping the persons are actually in process. They concern, either fixed workstations, or manipulators on electric wheelchairs. Other developments deal with assistance for piloting the electric wheelchair (following marks on the floor, piloting with ultrasonic transducer), for defining adapted programming language, for determining specific sensors to assist manipulation functions (grasping, handling, perception of space, etc).

The technologies to be set up are new, but do already exist. We need to gather the competencies between the different teams working on the mechanical aspects, the control command, etc and to transfer these technologies to the specific application regarding the handicapped persons.

The next step is to integrate these technical aids to form an integral aid which offers disabled people optimal opportunities in these four areas, so that they can function as independently as possible.
One must think in terms of an integral system for mobility and manipulation which comprises all the available technologies to enable the disabled person to communicate with, control and manipulate a structured-and-unstructured environment.

The integral system must be set up in such a way that it can be simply and independently controlled by the disabled person, great attention being paid to ease and speed of use.

To bring this project to a successful issue, three groups were organized to work in close cooperation, in the definition phase:

- a user group gathering important disabled associations in the Netherlands (VSN, STICHTING DE SCHAKEL), in France (APF, AFM/ CREATI) helped by two experts in the rehabilitation process (Dr. Busnel, Medical director of KERKPAPE centre (France) and Dr. Platts of the ROYAL NATIONAL ORTHOPAEDIC HOSPITAL (United Kingdom).

- A group of industrials dealing with these problems (POIRIER in France and EXACT DYNAMICS in the Netherlands).

- Two main contractors responsible for the research and developments (CEA/DTA/UNITE ROBOTIQUE in France and TNO-TPD/IRV in the Netherlands).

**Integrated Control of Manipulation, Mobility and Control of the Environment**

The execution of a task by a "healthy" person often depends on a combination of many different movements, using different parts of the body. A task can thus be carried out quickly and efficiently. Furthermore, many tasks are carried out without conscious thought with regard to the bodily movements.

In the case of a disabled person who cannot carry out the tasks with his body but must rather rely on all sorts of technical aids, such unconscious execution is (virtually) impossible. Often a variety of technical aids and equipment must be operated, all of which must be consciously controlled one at a time.

A technical aid can offer great help to a disabled person but can also encumber him/her with an extra handicap if it is too complicated, unclear or slow to use. In assessment studies of technical aids, it becomes apparent that this is often the case, the result being that the technical aid is used less often or sometimes not at all. The integral system will comprise many different technical aids and systems. One of the most important points of attention is integration of all systems employed. This is a pre-requisite for simple and optimal use of an integral system.

**Mobility**

The integral system includes a system with which the user can drive and manoeuvre in the environment. Careful attention must be paid to the manoeuvrability of the integrated system with respect to its use indoors. Existing wheelchairs sometimes leave a lot to be desired in this sense, so that the wheelchair can only actually be effectively used out of doors. As manoeuvring cannot always be carried out accurately, objects in the users' environment are damaged, sharp edges and protruding parts of the wheelchair often posing an extra problem in the environment.
Navigational systems could bring about considerable improvements here.

One can think in terms of systems which, for example, use sensors to prevent collisions between the technical aid and objects in the environment, by detecting a threatened collision and redirecting the technical aid. In the same way, a navigational system could also "steer" the technical aid through a narrow opening, such as a doorway.

In a structured environment, such as the user's home, this navigational system could be extended by applying systems which, for example, can follow pre-programmed routes without the user needing to steer the technical aid. Another option could be a system in which tracks are built into the structured environment, so that the technical aid can be "led".

**Communication**

The integral system must include the functionality of technical aids that enables the handicapped to communicate. Examples of such aids are speech generators, writing aids, adapted keyboard operations and also adapted telephones.

**Manipulation**

The manipulating system will be an important constituent of the integrated system. Many tasks can be carried out by means of a manipulating system which would otherwise be (virtually) impossible for a severely disabled person Not only with respect to GDN activities but also certainly with respect to working and recreational tasks. The manipulating system can thus considerably increase the independence and opportunities of the disabled person.

There are already a number of different manipulators available for the benefit of disabled people, though they do not yet enjoy large scale use. Research into their use has shown that a manipulator can considerably increase the independence of the disabled person. Such increased independence is greatly appreciated. A manipulator enables the disabled to develop a number of functions that can be divided into three groups:

vital functions: a manipulator enables the handicapped person to perform (to some extend) activities such as eating and drinking. Safety measures in case the safety malfunctions, should also be considered as one of the vital functions.

vocational functions: the manipulator enables the handicapped to perform a (professional) task

auxiliary functions: the manipulator enables the handicapped to perform trivial tasks such as inserting a tape in the tape recorder, picking up something from the floor, reaching door handles and light switches in unadapted environments, etc.

A number of aspects are mentioned which could be improved and which can therefore be seen as points of attention in the development of the integral system.

Firstly, the performance of the robot arm is sometimes found to be limited, particularly its reach and power. On the one hand, heavy objects cannot be picked up (more than 1.5 kg) but on the other, the power with which keys are pressed is difficult to control, so that they are easily damaged. The controls are sometimes awkward, especially where this is done by buttons, this means that procedures cannot be carried out in a smooth manner.

Procedures are carried out too slowly, so that use of the manipulator is fruitless, e.g. typing on a nor. ː typewriter or keyboard which has not been adapted. The number of words per minute is so low that such activities are not carried out. Another example is picking up the telephone. The connection has been lost before the user has got around to picking up the phone with the manipulator.

The speed and ease of use can be improved if procedures which are frequently carried out can be individually initiated by the technical aid in some way or another, rather than the user having to constantly steer the aid. A well known solution is to pre-program certain procedures. In an optimally integrated system, not only can the procedures of a single system be pre-programmed, but also procedures which are combinations of the various sub-systems of the integral system. In this perspective would the development of docking systems enable the ease of preprogrammed movements related to the structured environment to a great extend.

**Control of the Environment**

The integral system must include all sorts of systems in order to control the environment. These include remote controls, adapted communicative aids, such as a speech generator, writing aids, adapted computer keyboard operation, etc. These environment control systems will therefore control a large number of different pieces of equipment and aids.

Many pieces of equipment and technical aids have their own control panel which can be used to control a single device. If a second device must then be operated, the user must switch to a new control panel. This means that many procedures are necessary, which all require concentration (driving, poss. manipulation, operating equipment, driving again, switching, operating, etc.)
The ease and speed with which tasks can be carried out can be greatly increased if the various technical aids can all be controlled simultaneously via a single control panel. The user need then only concentrate on carrying out the task rather

than having to control all the technical aids.

**Control**

Control of the integral system must therefore be possible via a single control panel (interface). The controls would appear also to create great problems in a number of consumer articles, such as video recorders, stereo equipment and other equipment with many set-up and user options. The users therefore make use of a part of the options, because they do not understand the rest, the controls are not clearly organised, etc.

Via the control panel of the integral system, not only one but many more and also completely different systems can be controlled. This makes great demands on the informational ergonomic characteristics of the control panel.

**Conclusion**

First steps are made to the realisation of wheelchair mounted integrated control systems. The relevance of the integration and implementation aspects will be, among others, tested in the two projects although in a limited way. Safety issues, standardization, acceptance and dissemination have to be addressed in future projects in more detail.

Author's Address
Mr. J.A. van Woerden
Institute of Applied Physics
P.O. Box 155
2600 AD Delft
The Netherlands

# RUI: factoring the robot user interface

Larry Leifer
Center for Design Research,
Mechanical Engineering Design Division
Bldg.530, Duena Street
Stanford University
Stanford, CA 94305-4026

ABSTRACT

Shortcomings at the Robot User Interface (RUI) are major technical deterrents to widespread use of telerobots in health and human service. The basis for this assertion comes largely from experience in vocational rehabilitation and education [1]. Text, voice, graphic and kinematics command-control interfaces are cumbersome at best for robot programming. Master-slave (virtual reality) interfaces remain immature and are rarely appropriate where physical and cognitive limitations motivate the pursuit of robotic assistance in the first place.

Because most people want to use robots, not program or operate them[2], application development becomes the dominate part of the overall cost and support equation. Today, robot programming requires motion specification, planning and task supervision skills that take years to develop. Several factors should be addressed simultaneously to change this situation [3]. The issues are illustrated by the work of Stanford investigators working on visual language communication, robot learning, adaptive grasp, spatial reference designation, hybrid force-position servo control and fault tolerant system architecture.

GOAL

The goal of this paper is threefold. First, I would like to suggest that the Robot User Interface (RUI) has unique features that set it apart from the general area of Graphical User Interface (GUI) design. Second, the design requirements for this interface are outlined in relationship to manipulation tasks performed for vocational assistance. Lastly, I would like to introduce the reader to specific RUI projects at the Stanford Center for Design Research (CDR).

BACKGROUND

This project builds on 14 years of assistive robot research and development at Stanford University [4]. One result of the work is **Devar™**, a high performance Desktop Vocational Assistant Robot now undergoing clinical and field trials within the Department of Veterans Affairs. One of the important lessons from this work has been the realization that task programming is a serious bottleneck. It is also clear that medical and rehabilitation applications represent good opportunities for robotics technology in moderately structured situations.

Who are the users

It is striking how many people "use" the robot and influence the product definition (Figure-1). The impaired user is just one of these users. While automation tasks augment his or her performance, the way they are done is often dictated by therapists, administrators or others. One of the product realization lessons learned in another recent product development process [5] was the extent to which an assistive device must also support therapy. It is important to include product features that help care-providers measure cost, benefit and quality assurance variables.

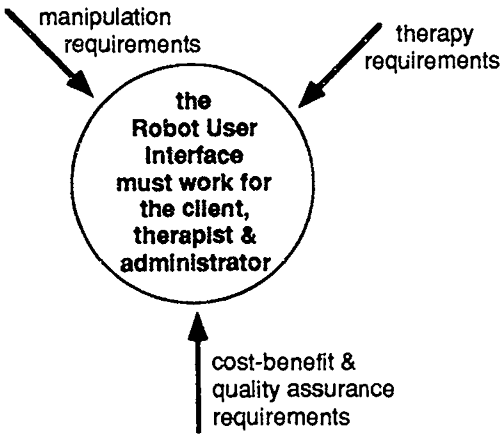


Figure-1 An RUI feature set must benefit each member of the care delivery team. Visual language communication features may empower the impaired user. Training and calibration modules support therapy and automated performance assessment reports enhance the therapist's productivity. The health care administrator benefits most from quality assurance features.

What differentiates an RUI from a GUI

User Interface Design is driven by several considerations. Five important factors for this discussion include: directness of manipulation; use of analogy and metaphor; understanding the user's cognitive model of the computational process; representing time; and representing space. While important for both GUI and RUI design, they are different (Table-1). In our experience, three of these factors dominate. Most importantly, the robot is a true 6 degree-of-freedom (DoF) system. Planning, coding and supervising of such systems is especially demanding (rather like operating a spacecraft). Furthermore, the robot is a dynamic physical system with real as well as computational time constants. It is capable of doing real work (including damage) without recourse to post-facto "undo" corrections. The sheer reality of an RUI dominates design trade-offs.

Task relevance of RUI design requirements

The Stanford-VA Devar project has implemented well over one hundred robotic assistance tasks over the past 12 years [6]. They fall roughly into three categories:

activities of daily living (ADL), vocational tasks and social recreational pursuits. Even the most structured desktop workstation environment requires tasks from each domain. Table-2 presents a quaiitative indication of our assessment of the importance of RUI design requirements according to the task domain. Note that ADL tasks are among the most demanding scenarios. Vocational tasks are among the least demanding, and their cost benefit cab be measured. Accordingly, the majority of our effort goes to educational and vocational applications.

| Generic User Interface Design Requirements | GUI Graphical User Interface Requirements | RUI Robot User Interface Requirements |
|---|---|---|
| Metaphor and Analogy | create symbols that evoke usable analogies and metaphors | create symbols that are consistent with manifest reality |
| Cognitive Models | visualize abstract representations for data & data processing algorithms | visualize real robot motion consistent with the user's own kinesthetic models |
| Direct Manipulation | create the illu sion that a symbo: directly manipulate reality | directly manipulate physical objects safely & reliably (remember, there is no post-facto undue) |
| Time | create the illusion of time | make the interface work in real-time |
| Space | 2 DoF, fixed point of view (eye to screen) | 6 DoF, variable point of view (end-effector to object) |

Table-1 A requirement matrix summarizes RUI-GUI design differences. Whereas the GUI designer tries to create the illusion of reality, the RUI designer must make reality accessible.

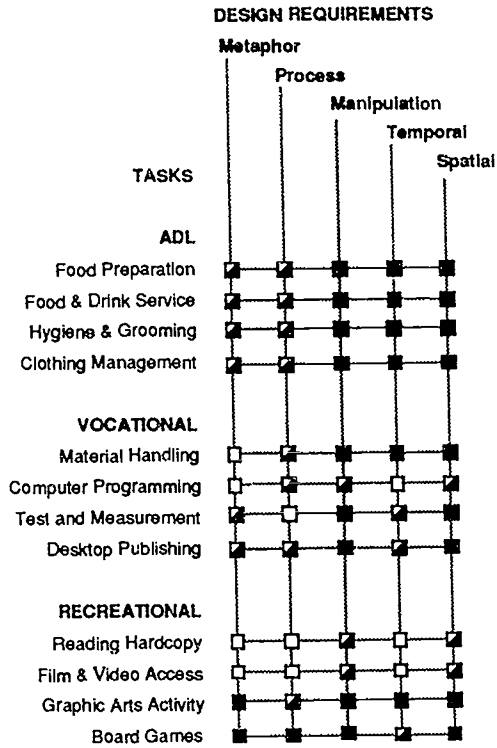


Table-2 RUI features should reflect the task at hand. No single interface paradigm can accommodate all of these scenarios. In our experience, the mouth stick and the robot complement each other as manipulation tools. Voice command, the pointer and the keyboard are similarly complementary.

## SYSTEM REQUIREMENTS

The conditions for effective use of robots in unstructured (or even moderately structured) environments are at least four fold [7]. The technical system must include one or more sensory modalities. The control architecture must support adaptive sensor driven motion control. There must be utilities for task and motion programming. A fourth, and rather subtle requirement is that these factors must deal with ambiguity. The collective importance of these requirements must be judged by the degree to which it is accessible to a wide range of operators, placing an additional burden on the RUI.

Robot programming languages (RPLs) have always presented the applications engineer with a deep dilemma. How does one use rigid RPL semantics and syntax to specify robot motion in an uncertain environment? Many investigators can testify that sensing the environment is just the beginning of adaptive control. In fact, sensor interpretation and multi-sensor fusion contribute massively to the RUI programming burden. Fault tolerance is often the first casualty of environmental sensing when sensor failure leads to undesirable robot motion.

## RUI RESEARCH PROJECTS at STANFORD

Figure-1 illustrates the strategic relationship amongst RUI research and development projects at CDR. The following narrative describes each issue briefly. Special attention should be given to visual language communication issues concerning RUI display design and in recognition that the robot is also part of the visual communication medium.

Visual Language Programming:

In a separate line of human-computer integration research, Richard Steele and collaborators [8,9] developed a visual language prosthesis, C-VIC, that has been proven to be capable of allowing globally aphasic persons (complete loss of natural language) to communicate better through the computer than they can through "natural" language. Experience with Lingraphica™, the commercial version of C-VIC, leads me to speculate that the communicative power of this GUI promises a substantial performance breakthrough in RUI design. Implementation of a test-bed system uses robot behavior specification icons with "readily inferable meaning" (RIM-icons). The linguistic notion of "readily inferable meaning" has a parallel in graphic representation (as in cartoons). This is a key feature of the lingraphic approach to robot programming. Figure-2 presents a few of the 2000+ iconic communication building blocks in Lingraphica™.

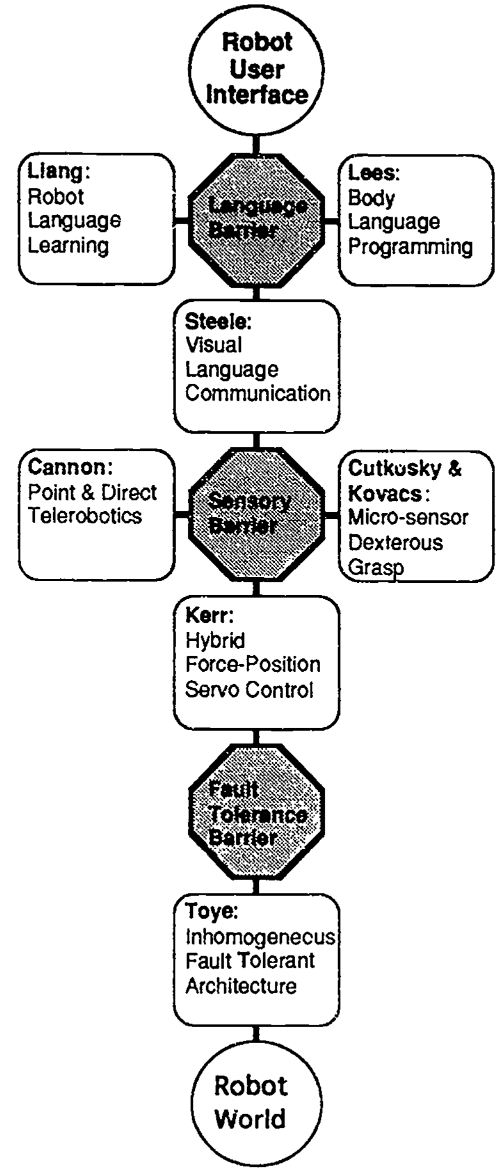


Figure-1 This is the road-map to research at CDR dealing with RUI issues. The barriers (octagons) are the natural language command-control interface, the robot sensing interface and the fault tolerant architecture. Individual research projects address the critical path to these issues (Steele, Kerr, Toye) or collateral factors (Liang, Lees, Cannon, Cutkosky-Kovacs).

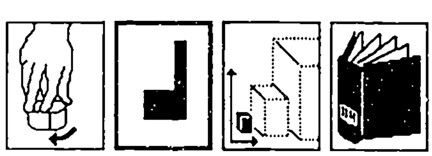

Figure-2 These icons include an animated verb to "turn", the preposition "against", the adjective "small" and the noun "book". When clicked, they reveal their meaning through graphic animation, spoken word, text and sound effects. A complete message is composed in storyboard fashion, "turn against the small book".

Robot Body Language Programming:

Building in part on Steele's work, David Lees [10] is developing a text-free robot programming environment. Key features of the environment include: a storyboard programming metaphor; graphic representations with readily inferable meaning; composition primitives; motion primitives; orientation primitives; grasp primitives; and environmental mapping. Whereas visual language programming uses a linguistic framework, body language programming uses a kinesthetic analogy. Motions are represented by animation with mime qualities. Gesture replaces words.

Robot Learning of Natural Language:

From our earliest work with voice recognition, it has been clear that the RUI should be as naturalistic as possible. After a disappointing adventure in classical natural language parsing, Liang [11] demonstrated robot learning of natural robot language commands. Their approach uses an axiomatic language model to learn by example and avoids the general requirement for prior understanding of syntax and semantics. Learning behavior was successfully demonstrated for English, German and Chinese instructions to assemble a simple bracket in Robot World, a multi-robot assembly system.

Dexterous Grasp Automation:

Many investigators have worked on grasp mechanics [11,12]. All conclude that sensory information from the point of contact with a grasped object is critical for both grasp assurance and dexterity. Cutkosky and Howe developed specialized slip sensors modeled after known properties of human tactile responses. Now, Cutkosky, Howe and Kovacs [13] are developing a micro-shear-sensor compatible with soft finger materials. However, it will be several years before robust, commercially supported, grasp automation will be available.

Point and Direct Telerobotics:

After several years in our clinical laboratory, David J. Cannon [14,15] decided to find a better way to designate way-points. They are the spatial coordinates required for task programming. This is an especially important issue with mobile assistive robots. One result of his work is a practical, moderately low cost, 3-D "mouse" that allows the user to specify the coordinates of a point, or virtual point, in the working environment (not just on the display screen). The approach supports "put that there" and "go around here" syntax commands.

Hybrid Force-Position Control:

Jeff Kerr [16] has made an especially useful contribution to a critical adaptive robot technology. His commercially available Zebra-ZERO manipulator is force and position controlled. Long the subject of laboratory research, this is perhaps the first human scale arm readily programmed to move in a desired direction with a specified force. This feature allows the programmer to imbed test conditions in the task code. Tests assure that operations continue as planned. If not, the robot explores the environment tactually and goes on if possible. An example from our work deals with diskette insertion and retrieval. A test case showed that force-position programming takes longer than position only control but that the tasks themselves are more robust.

Non Homogeneous Fault Tolerance:

After safety, no single factor has been more important in our clinical field trials than reliability. Not surprisingly, safety and reliability are strongly dependent on the same underlying technical issues. To date, most safety and reliability considerations have been passive. We are careful to build things with large safety factors. It is appropriate and timely to move forward with active safety and fault-tolerant control. George Toye [17] demonstrated a non-homogenous fault-tolerant architecture and operating system that could maintain normal operation of a prototype wheelchair in the face of sensor and actuator degradation and failure. The approach is compatible with manipulator requirements.

## DISCUSSION

The robot-user-interface presents many challenges. We may build upon advances in graphical-user-interface design but must go beyond them to explicitly address to the physical realities of robot teleoperation. I have described several lines of RUI investigation in our laboratory. Three should deserve your special interest: visual language programming; hybrid-force-position control; and fault-tolerance.

Cost-benefit evidence supports the value of assistive robot technology [18]. Now, the situation is one of continuing development and refinement based on user-centered design principles.


## ACKNOWLEDGMENTS

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## ADDRESS


Larry Leifer, Ph.D.
Professor, Director, Stanford Center for Design Research,
Bldg. 530, Duena Street,
Stanford University, Stanford, CA 94305-4026

Office: 415-725-0158
Fax: 415-493-6481
Email: lifer@sunrise.stanford.edu

# CONFIGURING THE MANUS SYSTEM

H.H. Kwee, M.M.M. Thönnissen, G.B. Cremers, J.J. Duimel, R. Westgeest.
Institute for Rehabilitation Research IRV
6432 CC Hoensbroek
The Netherlands


## Abstract

A review is given of the way n which the MANUS telethesis may be programmed to obtain a "configuration" adapted to a particular user. Configurations usually consist of different "modes", successively selected to gain control of various movements. Modes are programmed in the form of "patchboards", created on a PC with a "Patchboard Editor" out of "functions" from a library. A "Configuration Editor" permits one to create a configuration out of a set of patchboards. Once compiled, a configuration is downloaded into MANUS to define its human interface characteristics.


## Introduction

The MANUS telethesis was designed to be adaptable to users with different types of remaining control functions. Therefore, it must be possible to configure the MANUS system to be controlled by different types of input devices (controls) and adapt the control procedures accordingly. Furthermore, it should also be possible to adapt the system to individual user needs and evolve with him if necessary. For historical reasons, the first group of users for which configurations were developed consisted of persons with muscular diseases, still having limited finger movements available to manipulate controls.

To make this possible, the MANUS system was equipped with two microprocessors, one to take care of basic servo control functions, coordinate transforms, etc., and the other one with software to program the user control procedures. Since the MANUS telethesis was designed to be attached to the wheelchair, it has to operate primarily in an unstructured human environment, and most effort has been put into control procedures of direct interactive control of gripper movements by the user. In addition some limited "teach by doing" programming of points in space and of movement patterns will be added ultimately.

In this paper the present state of programming user configurations will be discussed. Only some of the characteristics of the interactive control of movements can be programmed today, corresponding both with programming of the transfer functions between user control inputs to gripper movements in space and with programming of the way different modes or menu pages are selected.

The objective is to make programming accessible to persons concerned with the functional rehabilitation of the user rather than to robotics and computer specialists. Therefore, it was decided to provide high-level instructions in terms of movements, rather than more versatile low-level ones more appealing to technically inclined people. For the latter group another set may have to be made available.

## General organization.

The firmware resident in the controller consists of a program capable of executing instructions given in the form of OPCODES, optimized for the interactive control of movements. A configuration can be downloaded into memory to define the transfer functions in the form of strings of opcodes. In order facilitate the creation of the downloadable file, a number of tools have been developed in the form of editors running on IBM-compatible computers.

To facilitate the definition of a configuration, different functional levels are defined:

- A **configuration** describes the complete set of controllable movements accessible to the user with the corresponding controls as input devices.
- A configuration consists of different control **modes**, corresponding with pages of a menu. A mode defines the transfer functions and/or the instructions accessible with the different user controls.
- A mode is programmed in the form of one or more **patchboards**. At this time a mode is described by three patchboards: a **pre-patchboard**, a **mode patchboard**, and a **post-patchboard**. Pre- and post-patchboards are the same for all modes, the mode-patchboard is particular for the corresponding mode.
- Patchboards consist of chains of **functions**, either linking input variables to output variables in more or less complex ways or defining actions to take place under certain conditions (e.g. to change mode or to move in a pre-programmed way).
- Functions finally, consist of a string of one or more opcodes, which can be executed by the controller.

To the programmer of user configurations opcodes are not made accessible and functions are the lowest elements he can use.

## Functions

Functions are made available in the form of a library and more functions are still being added to it. Functions may have one or more **parameters** associated with them. Different types of parameters may be distinguished:

- constants,
- variables, identified by a name to be given to them,
- patchboard names.

Different groups of functions exist at present:

**Initialization functions** activate a control procedure in the servo controller, thereby defining the coordinate frame in which movements are specified from then on (joints, cartesian, gripper referenced) or special procedures to be carried out (folding the arm out or in, calibration and tuning procedures). Some typical initialization functions are:

- init-joint
- init-cartesian
- init-grip-cart
- init-fold-out
- init-fold-in
- init-abs-zero

None of these functions has a parameter associated with it. Using an initialization function also introduces the names of the output variables (in a "memory map") that are made accessible to subsequent functions. This makes patchboard descriptions (see further) more readable and avoids errors of asking for the wrong output variables. For example, the output variables controllable after init-cartesian are velocities in cartesian coordinates:

- a0-speed: column up/down;
- x-speed: gripper towards and away from the user;
- y-speed: gripper right and left as seen by the user;
- z-speed: gripper up and down;
- yaw-speed: gripper rotation about a vertical axis;
- pitch-speed: gripper up/down about a horizontal axis;
- roll-speed: gripper rotation about its longitudinal axis;
- gripper: gripper opening and closing.

**Key interpretation functions** select the way in which key-strikes on a matrix keyboard (or switch activations) will be taken into account in subsequent functions. The corresponding functions are:

- key:while-down (as long as the key is being pressed)
- key:while-up (as long as the key is not pressed)
- key:going-down (the transition of pressing the key down)
- key:going-up (the transition of releasing the key)

The latter two only result in one short activation (one sampling period of 40 ms).

**Key action functions** read out the keyboard (or switch) inputs or use a key activation, interpreted following one of the four functions listed above, to control a movement output into one or more directions. Some typical functions are:

- 1-key-ctrl (key1,speed,output)
- 1-key-ctrl-add (key1,speed,output)
- 2-key-ctrl (key1,key2,speed,output)
- 2-key-ctrl-add (key1,key2,speed,output)
- 8-key-gain-set (mem1,mem2,speed)
- 8-key-ctrl (mem1,mem2,output1,output2,key1,...,key8)
- key-new-patchb (key1,patchboard name)

The function 2-key-ctrl sets the output variable to "speed" value in the positive direction when key1 is "activated" (see "key interpretation functions"), to "speed" value in the opposite direction when key2 is activated, or zero in other cases. If one wishes to add the effect of these keys to a previously defined value for the output, then the function 2-key-ctrl-add must be used. Similar functions exist for control with one key or with 8 keys, arranged in a relocatable square to simulate a joystick-like control. Key-new-patchb selects a new patchboard when the key condition is satisfied. Whereas for the first ones the condition will usually be defined by key:while-down, in the latter case key:going-up usually is more convenient in order to make sure that the next patchboard is entered with the key released.

**Proportional movement control functions** to use a proportional control input device like a joystick to control gripper movements in velocity or position control modes:

- prop-speed-ini (input channel,mem1)
- prop-speed-ctr (inputchannel,mem1,dead-zone,gain, output)
- prop-speed-add (input channel,mem1,dead-zone,gain, output)
- prop-pos-ctr (input channel,mem1,gain,output)
- prop-pos-add (input channel,mem1,gain,output)

These functions are largely similar to the 2-key-ctrl ones above. The initialization makes sure that the input value (e.g. joystick position) at the moment the mode is entered is taken as the zero reference for velocity control or, similarly, for the control of changes in position. This initial value is stored in mem1, a memory address to be named. For the -ctr and -add functions, a dead-zone value, a gain (between $\pm 1$), and the output variable must be defined as parameters.

**$I^2C$ functions** similar to the key- and prop- type functions have been developed (and more are still under development) to have the same possibilities with keyboards, switches and proportional controls communicating with MANUS through the $I^2C$ bus as an alternative input. New functions for this bus are output functions to control external switch functions or generate proportional output signals. These are particularly useful for interfacing with wheelchair control units. In a later phase similar functions are expected to be developed for communication with the "M3S" bus, developed for the wheelchair environment in a European TIDE project of the same name.

**General movement control functions**:

- do-not-move
- move-allowed
- reverse-move (output)
- gain-n (output)

The do-not-move function sets all output variables to zero and prevents any movement to be carried out, even if output variables are redefined by functions like those presented above. It does allow the redefinition of the output values, however. The move-allowed function removes the movement block and allows movements to be carried out as specified by the values of the outputs defined before this instruction or as modified afterwards. Do-not-move used in a pre-patchboard will reset all outputs to zero, but allows their modification in the subsequent mode patchboard (thereby always making sure that only actively changed outputs will be effectuated at the end of each sampling time of 40 ms).
The reverse-move and gain-n (n=2,3,4,5,8) instructions respectively change the value of the output into its negative value and in its n times amplified value, but limited to a certain maximum value to prevent overflow.

**Display functions**:

- display (code number)
- monitor-page (page number)

Display is used to define the 5x7 matrix symbol on displays on the arm and on an external display.

The display patterns have to be selected from a library, in firmware present in MANUS.

Monitor-page may be used to transmit a page number over the RS232 bus to an external PC, where it can be used by the IRV MANUS Monitor interactive teaching program to display relevant information corresponding with the present mode. The pages displayed are DOS files that can easily be made or modified in the field, both to document new patchboards and to facilitate training.

## Patchboards

The functions available in the library may be used to create patchboards for specific modes. For this purpose the **MANUS Patchboard Editor** program, running on a PC, must be used. This program uses a menu structure to select the different operations. It includes two types of HELP functions to get access either to relevant instructions on operating the editor or to the information included with each function in the library.

The Main menu of the MANUS Patchboard Editor gives access to the following options:

- Create new Patchboard (from scratch)
- Copy Patchboard (as a basis to create a new one)
- Edit (an existing) Patchboard
- Print Patchboard
- Edit/view Catalog (of presently existing patchboards)
- Exit

When one of the first three options is selected, variables may be defined and functions may be included, deleted or edited in the patchboard. Functions may be selected by a cursor in the library list presented on the screen. The editor also asks for the function parameters to be specified and allows to add comments.

**Example 1: Pre-patchboard for keyboard configurations.** It contains only three functions:
read-keys
do-not-move
end
It reads the matrix keyboard to prepare the use of the keys in consecutive mode- and post-patchboards. It also sets all outputs to zero and prevents any movement to take place at the end of the cycle unless allowed in consecutive mode- or post-patchboards, as mentioned under the "general movement control functions".

It also includes tables (not shown) to define the names of the keys of the matrix keyboard used in relation to their physical input connections to MANUS. Note that this definition is given in the pre-patchboard, of which there is only one in a configuration. In this way, it is possible to adapt a configuration to keyboards or switches with somewhat different connections and store pre-patchboards for different types of keyboards in a library for use in different configurations.

**Example 2: mode patchboard for keyboard-control of XYZ movements of the gripper.** It contains 15 functions and one "label":

```
init-cartesian
display (26)
8-key-gain-set (speed-x&y,speed-diagonal,10)
:start
BEGIN (:start)
key:while-down
8-key-ctrl (speed-x&y,speed-diagonal,x-speed,
   y-speed,key-2.2,key-2.3,key-2.4,key-3.4,key-4.4,
   key-4.3,key-4.2,key-3.2)
2-key-ctrl (key-3.1,key-4.1,10,z-speed)
2-key-ctrl-add (key-1.1,key-2.1,08,z-speed)
2-key-ctrl (key-2.1,key-1.1,02,roll-speed)
2-key-ctrl (key-1.3,key-1.4,08,gripper)
key:going-up
key-new-patchb (key-3.3,@PBJUMP)
move-allowed
monitor-page (0E)
END
```

The first three functions select the cartesian control procedure, set the display symbol, and define the speeds to be used later. These functions are executed only the first (sampling) time after the mode has been entered. The BEGIN (start) function makes the next cycle to begin at the :start position.

The key interpretation function key:while-down makes the following key action functions to be activated as long as a key remains pressed down. The names "key-n.m" of the keys used in the latter functions refer to row n and column m in a 4x4 matrix and have been defined in the pre-patchboard. Controllable output variables column-speed, x-speed, y-speed, z-speed, yaw-speed, pitch-speed, roll-speed and gripper were automatically defined by selecting the cartesian initialization function.

The 8-key-ctrl function controls gripper velocities in a horizontal plane in 8 directions with a velocity value 10, defined in the 8-key-gain-set function and transferred through their shared (memory) parameters speed-x&y and speed-diagonal.

Movement in the vertical (z) direction is controlled both by the first 2-key-ctrl function with keys 3.1 and 4.1. and by the following 2-key-ctrl-add function with keys 1.1 and 2.1. These latter keys are also used in the next function to control gripper roll (gripper rotation about its longitudinal axis). Pressing one of these keys therefore results in a simultaneous rotation and vertical displacement of the gripper, optimized to simulate a drinking movement, but also useful when pouring a drink into a glass.

The key-new-patchb function is preceded by the key:going-up function, and therefore is activated when key-3.3 is released. The patchboard to be activated has to be defined later with the configuration editor when all patchboards included within the configuration are known.

The move-allowed instruction finally authorizes the specified movements to be executed, in spite of the fact that not all controllable output variables have been defined here since the missing variables were already set to zero in the preceding pre-patchboard.

Patchboards are stored as separate files and included in the patchboard catalog upon their creation. The "Edit/view catalog" option of the patchboard editor gives access to the following selections:

- Import Patchboard
- Remove Patchboard
- View Description
- Edit Description

## Configurations

Configurations are created with the "MANUS Configuration Editor" program on a PC. The creation begins by selecting the patchboards to be included in the configuration from the catalog displayed on the screen. A configuration must contain an initialization patchboard defining start-up operations, a pre- and a post-patchboard, and one or more mode patchboards.

Once the patchboard set has been selected, the "patchboard jump" parameters have to be defined in all patchboards containing them. The selection is made with a cursor from the previously defined set of patchboards. A page of comments may be added at the end.

Another option in the configuration editor must be used to compile a newly created configuration file into a file downloadable into the MANUS controller. Existing configurations may also be re-compiled to update them when changes have been made within the patchboard files (as long as the transitions between the patchboards remain the same).

Finally, the MANUS Download Program is used to download the compiled configuration file into the MANUS system through a RS232 link. MANUS is then ready to operate with the new configuration. The RS232 link may or may not be maintained to run the MANUS Monitor program for interactive information about each of the modes used.

## Conclusion

With the editors and the function set available today it is possible to create or modify in a fairly simple way configurations adapted to different users of the MANUS telethesis. Today, most experience has been obtained with keyboard-controlled configurations, but the function set is gradually extended to include other control inputs.

Some user-unfriendly aspects still remain in today's editors, like the need to assign addresses to variables being defined and the use of hexadecimal numbers for parameters rather then decimal. In future updates of the editors and the firmware within MANUS these aspects will be gradually improved.

Nevertheless, experience will have to teach us whether and to what extent the objective of making programming of MANUS accessible to others than technically skilled persons can be reached. One option being considered is to have different levels of access to modifying and creating configurations, ranging from a limited authorization to modify some parameters within given ranges up to full access to all features. User safety, product liability, and warranty considerations are complicating factors in this respect.

## Acknowledgements

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## INVENTAID: TECHNOLOGY FOR THE DISADVANTAGED

Jim Hennequin
InventAid
Cranfield, Bedford, MK43 OHX, U.K.

### Introduction

Over the last twenty years medical science has made enormous progress in the treatment and rehabilitation of persons with spinal injuries. This means that there are an increasing number of people now surviving with only very limited movement, who would in the past have died. In some cases young people are condemned to life with only tongue, eye and head movement. This presents a new and urgent need, that can only be met by engineers and other professionals working together. This is a very real challenge, that must be addressed by the best minds of our generation.

InventAid was founded as a non-profit making organization to develop devices to help the disabled and especially for the spinally injured. In the past we have been funded by donations from ASPIRE, Comic Relief, and other charities and our workshop has been provided free by Spitting Image Productions Limited. AirMuscle Limited provide administration and accounting free and the directors Dr. Robin Platts and Jim and Yvonne Hennequin provide their services free.

### Wheelchair Mounted Manipulator

Over the last four years we have been developing a pneumatic wheelchair mounted manipulator arm for use by the paralysed and this is based on the Flexator* air muscle. This is a patented pneumatic actuator which is particularly suitable for use by the disabled. To test the suitability of the system a simple manipulator was made for a girl in North London, who has muscular dystrophy. This arm enables her to paint, eat and generally look after herself. Her wheelchair is fitted with a twelve volt compressor, air tanks and control system, and the system has proven itself by operating satisfactorily for two years without maintenance.

We have also completed several prototypes of the full manipulator arm, the latest of which will lift three kilograms from the floor up to four foot from the ground. It is sufficiently sensitive to pick up an egg and with only a few minutes training it is possible for anyone to lift a cup up to the mouth and drink from it. The system could be retro-fitted to almost any electric wheelchair and should not cost more than $4,800, when manufactured in quantities of 500 or more a year. The latest version has been on trial by tetraplegics in London and is now in production in Cambridge.

### Palatial Tongue Controller

Those with high neck injury, who only have head, eye and tongue movement, would be unable to control a wheelchair manipulator or any other device if we had not also developed a system to suit their needs. Devices, which make use of the movement to the head are not popular with tetraplegics because they are obtrusive and because they rob the individual of the last body language they have remaining.

Our director, Dr. Robin Platts originated the concept of a tongue controller and Matthew Steinberg and Jim Hennequin have been perfecting such a system over the last two years. This system consists of a dental plate, which is fitted to the upper teeth having small plates which are touched by the tongue. A minute receiver and transmitter signals the tongue movements to a coil worn around the neck and thence to the controls of the wheelchair mounted robotic arm. The tongue is a perfect muscle for the purpose of controlling devices because it is fast, accurate and hidden from view. The system has been proven to be viable and will be ready for production, when we have completed the miniaturization of the circuits for the receiver and transmitter. The system could also be used by paralysed people to control the wheelchair itself, computers, their environment and even motor cars. The palatal tongue controller is particularly useful to get the spinally injured back to work. Via our mouse emulator the paralysed person can use CAD, desktop publishing, wordprocessing, paintbox and many other computer systems <u>at the same speed</u> as every other employee. The InventAid tongue controller was a finalist in last years Archimedes Awards. Both our arm and the tongue controller are the only economically viable systems available in the world at present.

* The Trademark FLEXATOR is the property of AirMuscle Limited.

# HANDY 1 ROBOTIC AID TO EATING: A STUDY IN SOCIAL IMPACT

Dr. Marian Whittaker
C.A.S.E., Keele University
Staffordshire, ST5 5BG, UK

**Abstract**

Twenty users of the Handy 1 Robotic Aid to Eating were surveyed in order to gain information on user response to it. All had been users of the aid for more than three months. Data collection was by personal interview using an open-ended questionnaire, in some cases more than one visit being necessary to complete the interview. A number of issues were raised, some of which will mean adaptations to the design of the aid and a re-evaluation of the way in which training is provided for the users. The overall response was positive and the aid was viewed as an innovative and useful aid to rehabilitation.

**Introduction**

The work on the Robotic Aid to Eating began in October 1987 and the relatively simple design of the early days has given way to the far more sophisticated version known as Handy 1. Right from the beginning certain criteria were specified:

- The equipment must be relatively low-cost;
- It must allow a person to eat a meal unaided;
- It must allow the user to choose;
- It must offer the opportunity for increased dignity and confidence building.

The human element of robotics has received relatively little attention in comparison to the time and effort devoted to innovation and perfection in mechanical and electronic design. This is not only true of rehabilitation robotics, where, until recently, very few systematic surveys of user factors have been undertaken, but also of industrial robotics, according to a comprehensive review by McIlvaine Parsons (1988). This neglect of robotic users may be relatively unimportant in industrial settings where many tasks are pre-programmed in order to deliberately exclude human intervention but it is unthinkable to ignore the various potential user groups when designing applications of rehabilitation robotics: quite simply, if the machines are not used they are useless.

**Method**

Participants

In 1988, a survey of local schools and Adult Training Centres (A.T.C.'s) within a fifty mile radius of Keele had identified individuals who, it was thought, could benefit from the use of Handy 1. However, in addition to physical disability, most had learning difficulties ranging from moderate to profound and all but seven had severe communication problems. By the end of 1990, 36 aids were in regular use with 6 people having 2 each. Ages ranged from 4 to 82 years (Table 1).

Table 1. Age Distribution of Users

| Years | Numbers |
|---|---|
| Under 5 | 1 |
| 5-10 | 3 |
| 10-20 | 10 |
| 21-30 | 6 |
| 30-40 | 5 |
| 40-50 | 3 |
| 50-60 | - |
| 60-70 | 1 |
| 70-80 | - |
| 80+ | 1 |
| | 30 |

Twenty users were selected from this group to take part in the survey. This represented all those who had had the aid for more than three months. Where possible users were interviewed but more often the respondent was a parent, teacher, or therapist. All of the subjects had to have been either a user, or working with a user of the aid for 3 months or longer (Table 2). The range was 3 months to 2.5 years.

| Table 2. | Respondents |
|---|---|
| Users | 6 |
| Parents | 5 |
| Therapists | 4 |
| Teachers | 3 |
| Nurse | 1 |
| Centre Manager | 1 |
| Total | 20 |

The aids had been placed in a number of different settings. (Table 3).

Table 3. Location of Robotic Aids to Eating

| | |
|---|---|
| Schools | 11 |
| Nursery Schools | 1 |
| Private homes | 15 |
| Adult Tr. Centres | 2 |
| Hospitals | 5 |
| Residential Homes | 2 |
| Total | 36 |

It was noted that some settings were much better than others at accommodating and accepting the new technology. Those individuals gaining the most benefit from the aid were those using one both at school and home. The fact that they had chosen to have an aid in both settings reflected their preference for feeding themselves at all times if possible. However each place showed up its own advantages and disadvantages. What was common to each was that the aid had to be effectively managed in order for the user to gain the maximum benefit.

**Method**

Handy 1 was used for at least one meal each day by all respondents. Where the user had one aid at school and one at home, two meals a day were usually eaten with the aid. The meal most likely to be missed was breakfast.

A questionnaire was constructed. Specific questions were asked about initial reaction and training, where the aid was used and how often. The latter part of the questionnaire was left open-ended to encourage the users to discuss any issues they wanted to raise.

All respondents were approached by telephone and all agreed to take part in the research. Interviews took place in users' homes, schools, and hospitals.

**Results**

It is most convenient to present the results under three major headings. The acquisition of the aid, the aid in everyday use (housekeeping) and personal development. Some discussion of the findings will take place as issues are raised.

**Acquisition and Training**

Initial Reaction

For most of the respondents their visit to the clinic had been their first opportunity to see the aid. In every case there had been a matter-of-fact acceptance of it. They saw it very much as a means to an end - it was solely its functionality that interested them at this stage. They all felt that they had been given a reasonable amount of time to try it out and ask questions before deciding to proceed.

Seating

Five subjects stated that it was at this initial trial that they realised that they had seating problems. Because the spoon does not change its position in the same way that a human helper will accommodate shifts in user position it soon became apparent to them that their chair was offering inadequate support. These users were assessed for new bodyforms in their wheelchairs and it was brought home to us that when you change something in the environment there is a knock-on effect. Using the aid showed up strikingly how seating can became inadequate almost imperceptibly. The presentation of the spoon in the same position each time gave the users and carers immediate feedback on posture. Correct posture was not only more comfortable and made eating easier, but was also felt by the carers to improve eye contact opportunities.

Delivery and Training

The robotic aid was always delivered and installed. Training of the user and carer took place together. In some cases pre-training was needed. This was either learning to activate the single switch or practice at taking the food from the spoon.

Table 4. Satisfaction with Training

| | Very Satisfied | Moderately Satisfied |
|---|---|---|
| Users | 6 | - |
| Parents | 4 | 1 |
| Therapists | 3 | 1 |
| Teachers | 1 | 2 |
| Manager | - | 1 |
| Nurse | 1 | - |
| | 15 | 5 |

The users were satisfied with the instruction (Table 4). Some of the carers were using computers for the first time and these were the ones who felt that although their instructor had been willing to explain things to them as often as it took they still were not knowledgeable enough to deal with the unexpected.

All carers stated that the need for more information and skill became apparent as time went on. As long as the aid remained in the state in which it was delivered they were fine, but if they "got out of the program" they were stuck. During the course of the interviews a number mentioned that a manual and/or a training video would be useful. (These have now been produced. The Video is proving useful, but the Manual less so. The reasons most often given for this were that the Manual was kept in "a safe place" and they could not access it easily, but more importantly that if something went wrong it was always when a meal was being eaten and they did not want to keep somebody waiting with their food going cold while they ploughed through the Manual). The most recent suggestion, yet to be acted upon, is that a 'check-list of simple problems/solutions be produced on two sides of A4, covered in wipe-clean material and permanently attached to the aid.

While there was an overall favourable response to training all the carers interviewed thought that they would learn more if given the opportunity to be trained on the aid before they worked with their clients on it. They felt that if they built up their confidence they would be able to concentrate on improving the user's skills at mealtimes rather than concentrating quite so much on the aid. One carer felt that she transmitted her nervousness to the user and wanted to avoid this.

The carers themselves demonstrated a wide range of competence with the aid. 50% of the carers were in favour of attending a one-day training session at the University. Those who felt this was unnecessary were employed in teaching hospitals or day centres where technical back-up was available if needed.

**General Housekeeping**

The following issues were raised:

| | |
|---|---|
| Bulkiness | Ease of Use |
| Storage Difficulties | Hygiene |
| Destructiveness | Cost/benefit |
| Safety | Food preparation |
| Aesthetics | |

Some of the points made have been dealt with as the research has continued, although current users have not yet had the benefits fed back into the system. The latest version of Handy 1 is smaller, there are no trailing wires, it is encased in easy clean material, and it is easier to fold the arm away from exploratory fingers.

However, some concerns cannot be altered. For example, it can only be mains-powered, so that institutions worrying about trailing wires in a dining room, for example, will need to effect environmental changes themselves.

Cost/time effectiveness

Early in the development of the aid it had been postulated that savings in man-power would soon offset the cost of buying Handy 1. The equation is not so straight forward. Initially, extra time had to be allowed for training, and although the aid has an alarm button in case anyone should get into difficulties at any time, for the more severely disabled the carer was always near. One special school had three Handy 1's, which were used every day for meals and this had not led to any reduction in man hours served. It was not perceived as a threat by the carers, mainly because they viewed it as an extension and enhancement of themselves and not a replacement. Once the system was up and running they felt that the quality of the time was improved because they were freer to observe the child and felt that they communicated with the child more often than when feeding conventionally.

Where the user had earlier been able to feed themselves, the carers felt that some time was saved but more generally they reported that they could relax more over mealtimes. The time that they "saved" was not spent elsewhere, but they could go back to a mealtime routine closer to that pertaining before the accident or illness.

One child had been taken off a conventional feeding programme because his parents hoped that the robotic aid would be more beneficial in the long run. They had invested their time and energy heavily in the aid even going so far as to make a cardboard mock-up of Handy 1 before it was installed in order to get their child used to it. They were not interested in saving time but in using their time as effectively as they could. When interviewed they felt they had made a good decision.

Food

The users felt that there were no problems about the preparation and serving of food. Some foods such as soup were impossible but generally speaking they ate everything that they had eaten before. This was particularly true of children handicapped since birth. The spoon loaded most easily if there was gravy to help foods to cohere and the children with swallowing difficulties had always been fed in this way. One child in a hospital always had egg and bacon for breakfast. He also had cereal of a type which the aid had difficulty coping with. He got round this by eating the bacon with the aid, the carer then mashed up the runny egg and added cereal, the egg helped to bind the cereal and keep it on the spoon. On the two occasions when the aid was not available to him he still insisted on his cereal being prepared this way. The family above discovered that the aid coped very well with Chinese food. One mother was preparing a booklet on foods that work particularly well with the aid and the most attractive ways of presenting them.

Whilst types of food was seen as presenting few problems,quantity was a different matter. If the dish was not filled to the line marked, the spoon did not perform as well as it was capable of. This was particularly noticeable in the nursery school. The food did not fill the plate and although the child was making the right movements he was not being rewarded with a spoonful of food.

Safety

Safety concerns were expressed about Handy 1, but it was only in relation to trailing wires, people walking into the aid, or perhaps knocking it over. Where head spasms were likely to occur carers wanted to assure themselves that there was not enough force behind the robot to do any damage to the user.

Aesthetics

As the novelty of using the new aid wore off users and carers turned their attention to the aesthetics of it. Most of the respondents linked the looks of the aid to improving safety aspects, i.e. "..the food keeps falling on the keys and I'm worried it might damage the computer, it would be much better enclosed in a case of some kind." They all wanted the aid to be smaller and portability was deemed highly desirable. This contrasted sharply with their acceptance of it when first seeing it, but seemed to imply another kind of acceptance - that it was a permanent addition to the household so they would like it to look as pleasing as possible. On the whole they didn't want it to be made to look like anything else, it was what it was, but those in houses did take up a lot space in comparison to the amount available and all wanted the aid to be as compact as possible.

**Personal Development**

The following issues were raised:

| | |
|---|---|
| Freedom of Choice | Prestige |
| Self-confidence | Self-esteem |
| Improved head control | Improved mouth control |
| Naughtiness | Extra attention |
| Motivation | |

Freedom of Choice

This was rated highly by all of the respondents. The users appreciated the opportunity to take control because when one is severely disabled the opportunity for choosing is limited. The reliance on others to make choices for one was particularly irksome for those who had previously been able to feed themselves. The carers wanted to encourage as many different types of behaviour as possible, and the ability to make decisions of any kind was seen as being highly desirable. They felt that using the aid allowed users to make a decision and then immediately act on it. For the more severely disabled it was felt that the opportunity to exercise choice was not an option available to them very often and the fact that the aid allowed this was seen as a valuable contribution to rehabilitation.

Prestige/Ownership

In schools and hospitals where equipment was often shared the user actually had the exclusive use of the aid. This led in some cases to personalisation of the aid. One child with one at school and one at home named them Bill and Ben (well known puppets in England). One boy reported that his friends thought he was 'clever' because he was using a computer controlled robot and his carer thought that this positive reinforcement had spurred the child on to greater efforts. His position in the group had changed and he was keen to maintain his new status.

Self-esteem/Self-confidence/Motivation

Most respondents mentioned that they had noticed an improvement in one or more of the above. When asked to be more specific they found it difficult to put it into words, just a feeling that the user was more alert and more responsive. One carer specifically mentioned naughtiness here. She was caring for a child who was paralysed from the neck down and on a ventilator, but who took great delight in deliberately interfering with the set-up program on the aid so that she had to keep re-setting it. She compared it to her own childhood when she had flicked peas at her friends "Anecdotal evidence confirms that children appear to produce differential responses to the authority of the machine (computer) compared to that of humans." (Underwood & Underwood, 1990). In their study, young boys deliberately produced incorrect responses in order to have a severe reprimand printed on the screen. They felt that the opportunity to disregard an authority figure was almost a cathartic activity which they enjoyed to the full, and that the children in their study felt a sense of control when working with computers which was not achievable when adults took the role of computer (teacher). They postulate that such a sense of control ..."might lead to greater self-esteem and be motivating in itself." (Ibid).

Some users had started using computers accessed by single switch after using the one on the aid but one cannot assume cause and effect. When a person becomes the user of Handy 1 a lot of extra attention is focused on them and they respond to this. This is an area where more data is needed.

Improved Head and Mouth Control

When using Handy 1 the user may press the single switch up to 42 times each meal. He moves his head forward the same amount each time and the spoon presents itself in the same place each time. Some of the carers thought they noticed improved co-ordination as a result of this. They felt that they had observed a reduction in habits such as teeth clamping on the spoon.

This is an interesting observation. When fed by a carer the spoon is usually removed from the mouth but when using Handy 1 the eater has to remove his or her mouth from the spoon and they cannot do this until they let go with their teeth. The spoon will just wait there until the user gets the hang of how to do it. It never gets impatient and it never changes its presentation. When the user gets it right he or she is immediately rewarded with food.

Similar observations were mentioned over head control, firmer lip control and swallowing.

One carer had attempted to record improvement but the child she was working with was so severely disabled that it would take a long time for trends to show in the recorded data. Most carers said that they would be happy to record behaviour but with the exception of the therapists did not feel competent to devise an adequate scoring system. It became apparent during the course of these interviews that more detailed record keeping would need to be encouraged.

Six of the 30 original users have been unable to continue using the aid. As the study progressed it became possible to identify the factors influencing successful placement:

- Parental involvement must be strong;
- Keyworkers must be involved from the beginning;
- The younger the better (4 years onwards);
- Good initial assessment i.e.
    a. worked best with those who had never been able to feed themselves;
    b. least successful users were those with degenerative conditions;
    c. worked well with short-term users such as stroke victims working to regain use of their hands.

**Discussion**

The study of robots in a domestic setting is in its infancy. Clay, Hillman, Orpwood and Clarke, (1987) in their study of potential users of a robotic aid system, focused on the intended user population, what types of tasks robots would be expected to perform, what physical ability the user population would need to possess and whether people actually needed robotic help. Results indicated that there would be a potential market for a robotic aid system.

This study has taken the above survey a step further: the potential market transformed into an actual market. The Robotic Aid to Eating performs only one of the tasks mentioned as being desirable but it is felt than many of the points raised during the course of the study will be generalized to robotic placements per se.

Some specific recommendations on the placing of domestic robots can be made as a result of the findings of this study:

- That people be individually assessed;
- That adequate home/school support should be forthcoming.
- Training should be given to support staff before they introduce the aid to the user;

- Continued support should be available via training videos, manuals, checklists etc.;
- Careful monitoring of the removal of aids;
- Inclusion of interested professionals at all stages. They can make the difference between the success and failure of the introduction of new ideas;
- Third party observation of user/carer. Refinement of technique then become possible;
- Encourage record keeping as an aid to monitoring progress.

A study such as this one can only pick up impressions and point to the areas where further work is necessary. Because the employment of domestic robots is such an unknown quantity, particularly when used by handicapped people, it was felt important to keep this initial study fairly wide ranging. What did emerge was that at least three main areas of study need to be addressed more closely. Firstly, a more detailed study of the management of assessment and placement is needed so that valuable time and resources are not lost to those who will not benefit.

Secondly, a suggestion has emerged that there may be physical improvement to users of the aid and that some of the improvements may generalise to other areas of effort. If this could be demonstrated it could form the backbone to what some have suggested could be called "robot therapy". A study has already begun at Keele to test this hypothesis. It may be that Handy 1 has a useful place in a conventional therapy programme.

Thirdly, Baron & Greenberg suggest that performance and underlying self-esteem can be enhanced by inducing individuals to interpret failure as stemming from external causes. (Behaviour in Organisations, 1990) While there are obvious dangers of attributing all lack of success to other causes, it hardly needs to be pointed out that disabled individuals are more at the mercy of others than the general population, because they are less able to control their environment. It may be that when they are introduced to the robotic aid, which they can control, they can attribute their lack of success in eating unaided to factors outside themselves (i.e. society did not provide him with the right tools), and this may aid the development of self-esteem. This could be an interesting line of enquiry.

**Conclusions**

There are moral and ethical questions which need to be addressed. This is particularly true when parents are prepared to take children off established training programmes and substitute newer and relatively untried technology. It is also difficult when placing an aid such as this not to be aware of other things in the environment which may need to be changed - seating is but one example - and so care has to taken when dealing with other professionals.

What has become apparent is that the consumers of domestic robotic technology are naive consumers in many ways and it is therefore necessary for those at the forefront of designing and placing robotic aids to take the initiative in understanding their needs and designing for them. If an aid such as this is used to perform a function, the mere performing of that function to the best of one's ability has an effect on other areas of the user's life. This may be true of many activities, but the fact that the Robotic Aid to Eating has the ability to gratify a basic human biological need and appears at the same time to offer the opportunity to serve the gratification of psychological needs, means that this is an area worthy of further study.

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# INTEGRATING A MANUS MANIPULATOR AND AN ELECTRIC WHEELCHAIR. PRACTICAL EXPERIENCES

Tone Øderud & Jon Erik Bastiansen
Center for Industrial Research
Oslo, Norway

## ABSTRACT

Center for Industrial Research (SI) has in collaboration with the Norwegian wheelchair manufacturer Norsk Rehab Teknologi equipped an electric wheelchair with a MANUS manipulator. The MANUS is operated by four switches in the neck-support and the wheelchairs joystick. It provides the user with increased mobility and gives a feeling of being more independent. A workplace has been developed for a young person with a high neck injury. The work is mainly desktop publishing, and the person is using a Macintosh, a Headmaster with puff and sip control, voice input, a mouth stick for typing and the MANUS manipulator for fetching manuals, papers, diskettes and assisting copying and scanning. The paper describes the operation of the MANUS manipulator and the users experiences.

## BACKGROUND

Today there is a rapid development within the field of robotics and information technology, specially directed towards less expensive and more flexible solutions, and improvements in robot control and human-machine communication. This enable people with severe disabilities to perform everyday functions more independently and give them greater opportunities to participate in the professional life. In addition to improve the quality of each person's life, it will reduce the number of persons receiving disability benefits.

Robotics for disabled people are in some aspects significantly different from traditional industrial robotics. In industrial applications the robots are shielded from the operator. This is not possible when the robots have to be in close interaction with the user. Safety has to be of prime importance in rehabilitation applications.

## OBJECTIVE

The main goal of this project is to test out how a wheelchair mounted manipulator can assist a person with severe disabilities both in the professional life and in daily life.

This is split into 3 activities:
- Integrate the manipulator and the wheelchair and modify the user interface to the disabled abilities.
- Develop the workplace.
- Preprogramme sequences to be downloaded from a computer and stored in the MANUS memory.

The results are continuously evaluated through out the test period.

## METHOD/APPROACH

Basicly there are three different ways of applying robotics in rehabilitations applications: fixed working stations, wheelchair mounted systems, and autonomously mobile systems. The fixed working stations are often based on standard industrial robots. They are fairly cheap, very fast, easy to operate and easy to preprogramme. Unfortunately they have to work in a structured environment and they can only perform limited actions. A wheelchair mounted robot can be used in an unstructured environment and it gives the user greater flexibility, but it is more expensive and in general more complex to operate. Autonomously mobile robots are even more complex, and for this project we did not really consider these systems. We have chosen a MANUS manipulator because we would like to test the advantages and disadvantages of a wheelchair mounted robot operating in an unstructured environment. The MANUS manipulator was developed at the Dutch Organization for Applied Physics "TNO" and is now commercialized and manufactured by Exact Dynamics in the Netherlands.

To be sure that the results are of both practical and commercial interest, we started working with a young male person with a high neck injury (C4/C5) and the Norwegian wheelchair company Norsk Rehab Technology. In addition we have frequent discussions with TNO and Exact Dynamics.

The MANUS arrived in September 1991. Because the manipulator primarily should be used in unstructured environments, it was of main importance that the user easily could operate the MANUS. It was hard for the user to operate the original keyboard on the MANUS, but he could easily operate the joystick on the wheelchair. Together with the user and Norsk Rehab Teknologi we decided to operate the MANUS from the electrical wheelchair Zenit 4000. The original keyboard was replaced by control signals from the Zenit. Change mode and open and close gripper are controlled by 4 switches installed in the neck-support. Exact movements of the MANUS are controlled by the wheelchair's joystick. In combination with the joystick and the 4 switches in the neck-support, the user is able to utilize MANUS' 8 degrees of freedom. A display on the wheelchair control panel shows


**Figur 1.**
Using the MANUS at the workplace.

the actual mode. In addition to the direct control of the MANUS the user can select 10 different preprogrammed sequences from the switches in the neck-support. So far only the "fold in" and "fold out" procedures are implemented.

The user has been using the MANUS at work for about 1 1/2 months, and he will be using it for 4 more months. He has also used it at home for a short period. Next step is to make preprogrammed sequences. This will speed up the execution of specific tasks. The MANUS was supplied with a stand alone unit, and in combination with preprogrammed sequences it can give some of the advantages for fixed working stations. A stand alone unit for the MANUS and preprogrammed sequences can be of spesial interest at the workplace. The results are continuously evaluated throughout the test period.

RESULTS

A MANUS manipulator and a Zenit 4000 wheelchair are integrated and modified to meet the disabled person's abilities. The MANUS is operated by 4 switches in the neck-support and the wheelchair's joystick. In addition the on/off switch and the safety button is positioned on the wheelchair's control panel reached by the user.

It is of great importance that the user interface easily can be modified to the disabled person's abilities.

The experiences so far show that the MANUS provides the user with increased mobility and gives him better possibilities to perform everyday functions more independently. Similarly the Manus enhances his functionallity at work. But the MANUS needs to be tested for a longer period of time to see the long term results.

The MANUS is an advanced tool which the user needs some time to be able to operate effectively. Our user was a highly motivated young male. His interest proved to be valuable during the development phase.

DISCUSSION

The MANUS obviously has a lot of advantages. It gives the user increased mobility and the possibility to perform everyday functions more independently. So far the user's experiences are that a wheelchair mounted manipulator definitive is useful in unstructured environments. In addition to operate the computer at the workplace he can change diskettes, get papers, manuals and books, use the copying machine and get the Headmaster. At home he can for example put food in the microwave, take it out and eat it, drink from a glass with or without a straw, change CD-records and videotapes, get books and magazines and more easily use his computer. He lives by himself and he feels that a wheelchair mounted manipulator is more useful at home then at the workplace.

The disadvantages are that the manipulator adds more width and weight to the wheelchair, and makes it more difficult to move around. As mentioned the MANUS is an advanced tool and the user needs some time to get used to it. Occasionally the user gets tied of having the MANUS at the wheelchair for a longer period of time. In this project it was necessary placing both the manipulator and the joystick on the left side of the wheelchair. This was not the ideal solution for the user. As a general rule the joystick and the manipulator should not be on the same side of the wheelchair. It is therefore important that the user can choose between a right hand or a left hand mounted manipulator.

A special suspension element was delivered with the MANUS', and this made the manipulator easy to place on the wheelchair. The control box was put in a small bag at the back of the wheelchair. The modifications of the user interface were the most timeconsuming activity. This included integrating the MANUS and the wheelchair, installing the 4 switches in the neck-support, and placing the on/off switch and safety button within the users area of access. It is crucial for people going into this field not to underestimate the time that is required and the importance of adjusting and developing an individual interface to each user.

The Zenit 4000 has built in facilities for communication with external devices like manipulators and computers. The MANUS is also designed to be interfaced to different wheelchairs. Nevertheless, this project showed the needs for a standard digital communication interface between wheelchairs and manipulators and other additional equipment.

ACNOWLEDGEMENT

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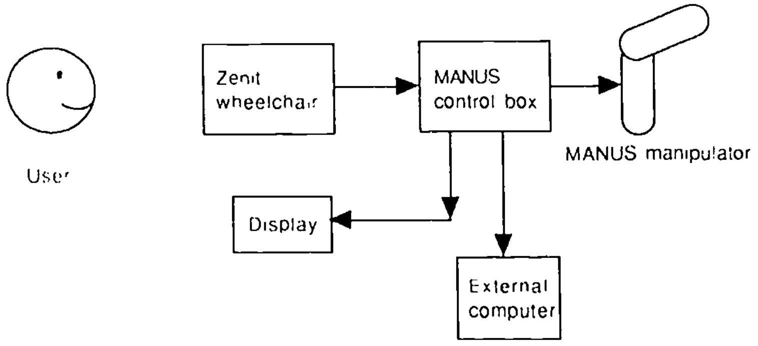
Authors address:
Tone Øderud
Center for Industrial Research
P.O.Box 124 Blindern
N-0314 Oslo
NORWAY




Figur 2. Block diagram of the system

# EXPERIENCE WITH THE NEIL SQUIRE FOUNDATION/REGENESIS ROBOTIC ASSISTIVE APPLIANCE

Gary E. Birch and Markus Fengler
Neil Squire Foundation
North Vancouver, Canada

ABSTRACT

The Neil Squire Foundation has been involved in the development of a robotic assistive appliance (RAA) for persons with severe disabilities for the past seven years. Currently, RAAs are in regular use with persons with disabilities at the following locations: Ecole Victore Dore, (School for Children with Disabilities) in Montreal; Lyndhurst Spinal Cord Centre, Research Department in Toronto; IBM Special Needs Systems Group in Boca Raton, Florida; and in a demonstration automated office at the Neil Squire Foundation in Vancouver. Recently, the first generation RAA has been transferred to the Regenesis Development Corporation (wholly owned by the Neil Squire Foundation) in order to facilitate commercialization and market delivery.

## 1.0 INTRODUCTION

### 1.1 The Neil Squire Foundation

The Neil Squire Foundation, a Canadian non-profit organization based in North Vancouver, has both service delivery and research and development capabilities and is well equipped to respond to needs of adults with severe physical disabilities. Service delivery programs include computer and technical assessment and training and an employment training program called Creative Employment Options. Research and Development projects include: development of a robotic arm; an environmental control system; various computer access programs; remote gateway and automated home; and a literacy program specifically designed for persons with severe disabilities.

### 1.2 Robotic Assistive Appliances for Persons with Severe Disabilities

The Neil Squire Foundation has been involved in the development of a robotic assistive appliance for persons with severe disabilities for the past seven years [1,2,3,4]. All research and development activities undertaken by the Foundation, the robotic appliance being the largest in scope to date, are conducted as applied research projects designed specifically to meet the needs of severely disabled users.

The first step in the development of The Neil Squire Foundation robotic assistive appliance (RAA) involved an extensive survey of previous work, in particular, that of Palo Alto VA Medical Centre[5], and Johns Hopkins University[6]. Subsequent surveys included work carried out by Georgia Tech[7], Stanford University[8,9,10], PRAB [11] and Boeing[12]. The initial survey was followed by interviews with several severely disabled potential users, occupational and physical therapists, and service delivery specialists.

As a result of these surveys and interviews the key features in the design of this first generation RAA were determined to be: functionality based on the users needs and wishes; low cost; ease of use (operates using a user-friendly computer software program); fully programmable (by either the disabled person or by an attendant); user safety; portability; (robot weighs only 18 lbs.); flexibility in RAA configuration; and reliability.

The basic reasoning, which led to the horizontal axis/cylindrical coordinate geometry of the RAA, was to create a manipulator that was work station located, could perform similarly to an attendant and was human size in scope. This led to mounting the arm on a horizontal bar which allows for sideways travel over a work table and the ability for the arm to rotate underneath so that it can access items stored at the back of the work area. The resulting RAA has six degrees freedom as well as a seventh for end-effector actuation.

The RAA is generally operated using a unique program called FLASH which runs on any IBM PC compatible computer. This software program is designed to act as a user friendly interface for persons with disabilities, as well as able-bodied persons. The computer, through a serial interface link, communicates to the robot through a low level controller.

Users who are disabled access the computer using one of a number of special input devices. Persons with adequate motor control may use the standard keyboard with the assistance of a handstick, mouthstick or headstick. An expanded keyboard can be used by persons with reaching capabilities, but with poor accuracy control. Persons with limited motor capabilities may use a pneumatic breath switch to activate a Morse code keyboard emulator. In the most severe cases, the disabled persons may use whatever motor control they possess to activate a single switch closure to select commands from a scanning system built into FLASH. Voice recognition systems may also be effectively used by persons with vocal capability.

FLASH allows the user to move the robot using programmed tasks, direct control or master slave control. FLASH also allows the user to program and edit tasks. The robot can be programmed, either by the disabled user or by an attendant, to perform such tasks as:

- fetching a book, opening it and turning the pages
- loading and unloading a computer disc
- taking paper out of a computer printer
- loading paper into an optical scanner
- extracting and returning files to/from a file storage system
- serving a drink

Clinical testing on the RAA was carried out before the final development phase to ensure user feedback was incorporated before it was finalized as a product and introduced to the market. This NHRDP supported clinical evaluation of the robot was completed approximately two years ago in a 15 month project involving 15 persons with severe physical disabilities and 4 able-bodied attendants [13]. Trials indicated that user response is very positive on the capabilities of the device. The major areas identified through the clinical evaluation process which required further attention were related to safety, the low-level controller, the end-effector, cosmetics, and certain aspects of the user interface. Recently, work addressing these areas has been carried out and now this first generation RAA has been transferred to the Regenesis Development Corporation (wholly owned by the Neil Squire Foundation) in order to facilitate the commercialization and market delivery of the RAA. Currently, RAAs are in regular use at the following locations: Ecole Victore Dore, (School for Children with Disabilities) in Montreal; Carleton University, Department of Computer Science in Ottawa; Lyndhurst Hospital, Research Department in Toronto; IBM Special Needs Systems Group in Boca Raton, Florida; and in a demonstration automated office at the Neil Squire Foundation in Vancouver. The use of the RAA with persons with disabilities is described in the following Section.

## 2.0 CURRENT IMPLEMENTATIONS

### 2.1 Ecole Victor-Dore, Montreal

Victor-Dore is a school for physically disabled children. The school purchased an early version of the Regenesis RAA in 1989. The robot is being used by children to move objects around on a large play table which consists of a village scene with toy people and animals. The table also has a toy train running on it which the children control in conjunction with the robot. Part of the work is to teach children spatial relationships between items and how relocating such items affects their appearance. It is also used to provide children with the capability of physical control of their surroundings.

The manipulator was customized to enable it to reach all points of the 10' x 7' table. It consists of a standard manipulator with extended horizontal travel mounted to a custom built overhead linear drive. The overhead drive is driven by the eighth channel of robot controller. Each of the eight joints is a different colour and students use a lazy susan with eight correspondingly coloured switches to activate individual joints directly. In addition, a special control interface was developed to allow single switch users to control the robot and the train. The system is currently being used in direct control mode in which the student selects, moves and stops joints on the robot using single or multiple switches.

### 2.2 Lyndhurst Hospital, Toronto

The Research Department at the Lyndhurst Spinal Cord Centre, purchased a Regenesis Robotic Appliance (RAA) in 1990. Researchers Jacob Apkarian and Tom Nantais used this RAA in a workstation environment. Their main interest was to compare the effectiveness and user preference for controlling the robotic appliance between a task command language, developed by them at Lyndhurst, and direct joint control. They used the RAA with six participants in a laboratory setting under the supervision of an Occupational Therapist. The participants were quadriplegics with spinal injuries ranging from C4 to C6. In all cases they used a DragonDictate Voice input system for the user interface. In addition, the RAA was placed in the home of two of the participants for two weeks each, again under the supervision of an Occupational Therapist. The home setting allowed for more flexibility by allowing the participants the freedom to try new tasks of interest to them.

Their results indicated a preference by the users for the task command language. Overall, the researchers felt that the major shortcoming of this system, as revealed by these evaluations, was the inability of the system to know the status of the operands in a task (eg.position and orientation of an object in the gripper). They plan to address this shortcoming in future research by utilizing video photogrammetry which could provide this type of information to the RAA control system.

### 2.3 IBM Special Needs Systems Group, Boca Raton, Florida

IBM is setting up Ken Glad, a University of Florida engineering student, with equipment and software which help overcome problems presented by the student's quadriplegia. The group purchased a Regenesis RAA in September 1991 and are integrating it into a home office in which Ken can complete homework assignments. The robot will be integrated with IBM equipment and software. This project is being carried out in conjunction with the Department of Electrical Engineering of the University of Florida.

The manipulator is a standard 6 degree of freedom model with horizontal travel extended to 118 inches.

The tasks that the robot is anticipated to perform are fetching of books, files and papers, turning pages and handling diskettes. At the time of writing, Ken's needs were being assessed and the robot was undergoing initial evaluation in the Communications Laboratory at the university. Chuck Eubank, an electrical engineering student at the university, is working with the robot and will be setting up the workstation for Ken. Other tasks will be included as necessary. IBM's involvement is being coordinated by Carol Esser, Project Officer and Walt Nawrocki, Product Manager.

### 2.4 Neil Squire Foundation, Vancouver

#### 2.4.1 *Automated Office Development*

Recently the Neil Squire Foundation was funded by Labour Canada, and received donations from IBM Canada and Herman-Miller Canada, to develop an automated office workstation that could address employment barriers for persons with severe physical disabilities. This project involved integrating both the latest in specialized technologies specifically designed for those with physical disabilities and technologies available on the common market. This included a 30,000 word voice recognition system, the Neil Squire Foundation's robotic arm, the Georgia Tech motorized file management system, morse code access to a computer, and an optical character reader.

The goals of this project were; to establish a demonstration office for employers to show that adults with severe physical disabilities can participate as contributing members in the work force; to enable the disabled workers to have efficient and integrated access to the various office equipment and to related technical aids needed in the operation of such equipment; and to demonstrate the office to employers in the greater Vancouver area through a formal presentation.

With all of the components in place an individual with a high spinal injury, can independently access many commonly used office tools. The user controls the computer using a voice recognition system and sip and puff morse code. The computer controls the robotic arm, the optical character reader, and the telephone. Files can be manipulated, books can be retrieved, and pages can be turned by the robotic arm, and facsimiles and phones calls can be made independently.

Currently, this demonstration office workstation is on a tour of public venues in several cities across Canada.

2.4.2 *Current Workplace Scenarios for Persons with Severe Disabilities*

At the time of writing we are just beginning an evaluation project on the RAA in vocational workstation environments. The overall objective is to demonstrate to workers who are severely disabled, rehabilitation professionals, insurance agencies and health care funders the potential effectiveness of a Robotic Assistive Appliance (RAA) in real work environments. This will be achieved by conducting evaluations to obtain qualitative and quantitative data regarding benefit and cost issues for disabled persons using the RAA in these work environments. By June of 1992 we will be mid-way through the first phase of this evaluation project.

Currently, very few persons with severe disabilities are gainfully employed. Typically, those who are working will have either an attendant or a co-worker available to them at all times to help them with work related tasks and personal needs. Usually, personal needs can be handled at one or two specific times during the work day (eg. lunch, coffee breaks) but work related assistance could be required at any time. It is expected that a workstation based robotic device can be used for work related task assistance and that the need for assistance by another person can be limited to personal tasks that could be scheduled at convenient times during the working day.

This evaluation project will equip a workstation at the Vancouver site of the Creative Employment Options program with a Regenesis RAA. Adults with severe physical disabilities who want to be involved in the work force will be the target group for this study. Six severely disabled workers will be selected to participate. Our resulting sample of participants will be representative of the population of potential RAA users in vocational applications. They will be participants in the Neil Squire Foundation's Creative Employment Options program and will become part of this study as a component of their training in the employment program. Due to practical limitations of resources and program size, the total number of six participants will be made up of two groups of three (Phase I and II). All six of the participants will be involved in performing real office oriented work in the framework of the Creative Employment Options Program.

Each participant will be in a cycle where they spend one day with the RAA and then two days without the RAA. Only during the job specific time will the daily work experience be monitored. In the condition without the RAA, only one day out of the two days will be monitored. The monitoring of the daily work experience for both Phase I and II will last for three months. During the work experience sessions, the attendant will be available to assist the user at any time. In the condition with the RAA, the users will be instructed and hence expected to use the RAA but they will be free to ask for attendant intervention if the users feel that it is required.

The following daily measurements will be taken during the work experience sessions:

a) Number of times the RAA used.
b) When the RAA is used, what is it used for? For example:
- b.1) Files
- b.2) Book retrieval
- b.3) Page turning
- b.4) Page retrieval from scanner or printer
- b.5) Drinks

c) Number of attendant interventions (with RAA and without RAA where applicable)
- c.1) due to failure of robot to perform task (eg. dropping fileholder, missing a page turn, etc.) and participant unable to correct by themselves
- c.2) due to users preference (even though the robot could perform the task)
- c.3) length of time of each intervention
- c.4) time since previous intervention

d) Time required to perform individual robot assisted tasks.

## 3.0 CONCLUSION

The research team at the Neil Squire Foundation has brought this first generation RAA to the point where it can be used by ourselves and other research oriented organizations to evaluate its usefulness and to provide critical feedback. As we begin to collect feedback from the various sites where the RAA is being used we will begin the task of designing a second generation RAA. Based on the initial feedback that is already available, we can see that although this application of robotics still holds promise there are many challenges (not all technological) to be overcome before we will see robotic assistive devices as a common and accepted tool for persons with severe disabilities.

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Gary E. Birch
4381 Gallant Avenue
North Vancouver, B.C
Canada
V7G 1L1

AN EVALUATION OF THE MANUS WHEELCHAIR-MOUNTED MANIPULATOR

G.Verburg, M.Milner, S.Naumann, J.Bishop, O.Sas
The Hugh MacMillan Rehabilitation Centre (HMRC)
Toronto, Canada

Abstract

Seven adults and five children have used the MANUS arm for assessment and training in the laboratory or in their independent living, working, hospital or school environment. This two-year R&D project resulted in the development of new data gathering and analyses methods, the adaptation of existing control interfaces and the development of a retractable wheelchair mounting system. Questionnaires and observation scales were designed and administered to each subject.

Introduction

The MANUS robotic arm is a wheelchair mounted manipulator arm designed and developed by a Dutch R&D Consortium [1] explicitly for use by persons who have severe physical disabilities. Robotic manipulator arms such as the MANUS offer the potential to supplement Activities of Daily Living (ADL) for persons with a variety of physical impairments. Potential MANUS users typically have limited control or strength of their arms and hands which places many tasks of daily living beyond their independent execution. In this research project, the MANUS manipulator is being evaluated in independent living, vocational, and school environments.

Objectives of the MANUS study are to:

- evaluate the usefulness of an advanced model of a wheelchair-mounted manipulator arm in the home, school, and work environment;
- study how the arm is used by analyzing specific activities of daily living such as eating, pouring a drink or handling objects;
- identify potential enhancements to the user interface through hardware or software adaptations;
- analyze arm utilization in order to identify common command sequences that will allow the implementation of a degree of task control in addition to direct control.

Technical developments

The original MANUS arm is controlled through a 4 x 4 keyboard or an analogue joystick. Several command modes control different aspects of manipulator operation e.g. arm position in 3D space, gripper orientation, and gripper opening and closing. Mode status is displayed on an LED display.

To perform the analyses of MANUS activities a data collection and analysis system was designed and constructed by HMRC staff that gathered information about: (a) the commands given to the arm; (b) the actions of the manipulator itself; and (c) the objects acted upon. A video recording system operated by a microcomputer device was designed to collect all this information. The criteria for the monitoring device were:

- command inputs to the arm to be sampled every 40 msec. minimum while the arm is being operated;
- events to be captured, timed, and stored for later analysis;
- manipulator arm actions and command signals to be recorded;
- synchronized video and command information to be recorded to correlate task activities with command strings.

The audio tracks on the stereo Hi8 video tape provided a convenient media for storing the command information captured while at the same time synchronizing the command data and video images. Mode information was encoded in the data stream stored on the audio track. A more detailed description of the hardware and software developments can be found elsewhere in these proceedings (Bishop et al).

Existing **control input devices** such as the Unicorn expanded keyboard and Nintendo Hands-Free Controller were adapted to the MANUS. In addition, adaptations were made for joysticks of Invacare, Everest and Jennings, Fortress, and Orthofab wheelchairs for their users to be able to control either the wheelchair or MANUS.

Methodology

Subjects participating in this research ranged in age from 11 to 50 years and had diagnoses of Duchenne muscular dystrophy, cerebral palsy, dystonia, spinal cord injury and, congenital amputation. Training occurred in the laboratory and at home. The actual evaluation took place in the laboratory, at home, at work, and in school environments.

Evaluation methods and tools included the Revised Barthel Index and the Functional Assessment Inventory [2] and the command and activity monitoring system developed at the Centre. Hardware and software were designed that enabled data to be down-loaded from videotapes into the computer and annotated. The annotations were also stored in computer files. After merging the files it was possible to analyze the numerical and character information to obtain common command sequences used for such acts as eating, moving the arm to a set position, and rotating the gripper.

**Results**

This study has identified four categories of results:

- Case Historical: e.g. lists of activities, positive features, problems, successes;
- Prescriptive: "Who are the best candidates for this technology?";
- Tool development: e.g. evaluation tools, methods, and protocols;
- Product improvements: suggestions for a better device, and user interface adaptations.

In this paper results from the first two categories only will be presented.

**Case Historical**: e.g. lists of feats, problem lists. activities that persons want or do not want to perform with the manipulator, reasons for success and failure, and records of significant events.

As the evaluation of the MANUS manipulator arm continued, the participants performed more complex and more interesting activities with the MANUS arm. Relatively common activities such as pouring, drinking, eating, and picking up objects were performed routinely. The **feats** presented below were special to the user and to project staff:

- for the first time in 40 years, independently take a bite of a sandwich;
- break an egg en route to making an omelette;
- peel a banana;
- operate a microwave;
- feed a butter tart to our welder;
- comb hair by drawing hair through comb;
- pull on a T-shirt;
- turn lights on/off;
- insert 5 1/4 inch diskette into a computer disk drive and close the door;
- lift up Toronto telephone book (2.4 kg);
- paint a picture (in rather cubistic style);
- user took picture of himself with the MANUS.

In the course of this study the **problem list** waxed and waned as new problems were encountered and older ones solved. The most recent problems concerned the "soft touch" of the MANUS. Soft touch refers to one of the built-in safety properties of the MANUS which consists of a relatively low clutch slip-level. Thus as soon as the arm or gripper encounters an obstacle or must exert a large amount of force the couplings are designed to slip, thereby reducing the amount of force applied. This "softening" of the mechanics of MANUS is intended to reduce the likelihood that the arm will damage the user, other persons or things in its envelope of operation. However, the slipping clutches literally allowed things to slip from the MANUS' clutches (gripper) and caused the MANUS to not always be able to generate sufficient force to perform essential activities e.g. open the fridge door, open a bottle or turn a door knob. For each of these activities we have found "tools" or "tricks" to successfully accomplish them with the MANUS through enhancing leverage, friction or with the help of one-handed assistive devices.

The trade-offs between **safety and power** or **safety and proximity** are two of the basic paradoxes that must be resolved in rehabilitation robotics. We must have safety of operation yet the manipulator must be sufficiently powerful to perform all required ADL activities preferably without "tricks". Removing the person or user from the manipulator's envelope of operation would dramatically enhance the safety of the manipulator system, but at the same time would reduce its usefulness to near zero.

What do people **want to do** with the MANUS? One of the questionnaires administered contained a list of 116 activities, distributed over 12 categories. All subjects were asked to indicate which activities they wanted or did not want to do with the MANUS arm. Our analysis afforded a tabulation of desired activities.

A preliminary listing of activities that were most highly rated as acts that our participants wanted to do follows:

The highest priority items were: fetching objects from shelves which includes picking up and placing books, manuals, and sheets of paper. The next most highly rated items were: operating a wall switch, plugging in devices, and pouring liquids. Finally a large group of actions that were chosen by half of our subjects included: eating and drinking, making coffee, opening a chocolate bar, brushing teeth, washing and drying one's face, turning knobs, and opening cupboards and doors, and playing board games.

Preliminary prescriptive information about prospective users; "Who are the best candidates for this technology?";

Information has been collected about the decisions to accept or not to accept this manipulator technology. The primary decision was based on the trade-off between benefits and efforts, i.e. the choice between what the arm was able to do for the user and how much time, effort, and inconvenience it cost to do it as opposed to, for example, asking someone else for assistance. As an initial attempt at quantifying this demarcation line it may be possible to use the scores on one of the standard instruments i.e. the Revised Barthel Index. Specifically, the persons who stated that they could benefit most from this technology had a Revised Barthel score of less than 40, indicating severe physical impairment.

Practical limitations such as accessibility issues, e.g. door widths, or control input options were important considerations which prevented some of the potential users to accept the manipulator technology on their chair and/or in their homes. It is expected that this study will begin to delineate some of the issues that are relevant for prescription decisions and criteria.

**Future Plans/Needs: Three Paradoxes**

As indicated already potential paradoxes exist around the safety and usefulness of this technology. There are other equally challenging paradoxes. The one that our colleagues from Lyndhurst hospital [3] stress is the paradox of versatility of the manipulator and the complexity of control. The more a manipulator can do the more complex its control commands or the more extensive its command menu become. The challenge posed by this paradox is to attain a reduction of the control burden, either through an increase in the robot's "knowledge of the world" or through allocating some intelligence to the world itself.

Finally there exists a paradox that has to do with perceptions and expectations. In our study we found a big difference between explicitly stated expectations, which we found to be fairly realistic, and a different - more subconscious - stratum of wishful thinking which is based on the kind of robots which only Hollywood can produce at the moment. In this battle between the wishful and the real it is often the wishful that determines the course of action followed. Against these "Hollywood odds" rehabilitation robotics must deliver real, practical applications, slower, less clever, less dextrous, less glamorous, but real and, if we succeed, really useful.

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Authors' address:
Research in Cognitive Development Group
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, Ontario
M4G 1R8
CANADA
E-mail verburg@ecf.utoronto.ca

# — REAL USERS — REHABILITATION ROBOTICS AT THE PALO ALTO VETERANS AFFAIRS MEDICAL CENTER

H.F. Machiel Van der Loos

Rehabilitation R&D Center
U.S. Dept. of Veterans Affairs Medical Center
Palo Alto, CA

Department of Mechanical Engineering
Stanford University
Stanford, CA

ABSTRACT

The Palo Alto VA and Stanford University have co-sponsored rehabilitation robotics since 1979. The primary focus has been on the design of voice-controlled workstations for people who have high-level spinal cord injuries. The tasks range from daily-living and recreation to vocational support. The users in our clinical studies have been VA in-patients of all backgrounds; for our vocational studies a number of veterans working in computer-related fields have served as test subjects.

BACKGROUND

In 1979, the Rehabilitation Robotics Program at the Palo Alto VA and Stanford University began work on a voice-controlled manipulator system for individuals with severe physical disabilities such as quadriplegia caused by spinal cord injury. Our vision in the intervening years has not changed. Initially, the project was severely constrained by the lack of reliable, high-quality technology. Real-time operating systems, voice input and output systems, microprocessor-based computers, and appropriately scaled robot manipulators were just breaking into the consumer and industrial markets. Until 1987, our project performed clinical studies exclusively in-house, largely due to the experimental nature of the robot system [1].

In 1987, the initial robot system, based on 8-bit microprocessors and rudimentary user interface components, was replaced by a new generation of technology. Software development tools and personal computers made it possible to provide a color display, digitized speech output, phone line handling, and robust voice recognition in a reliable package. Coupled with an upgraded robot, the PUMA-260, the system is capable of performing desktop tasks reliably, quickly, and safely. It has evolved over the past years and exists today as the Desktop Vocational Assistant Robot: DeVAR [2].

During the early years, we placed a great importance on User-Centered Design: closing the design loop around the end-users of robot systems. Through workshops, seminars, interviews and exposure to our prototypes, individuals with quadriplegia, as well as their attendants and families, provided first-hand descriptions of needs for daily-living and vocational support, and provided the basis for task choice and design decisions. This approach has consistently been very important for our program.

Equally important was the conviction that a rehabilitation robotics team had to consist of engineers and clinicians in an environment as close to a target population as possible. While the development work proceeded at Stanford University in the Department of Mechanical Engineering, clinical development and evaluation was based at the Palo Alto VA, in the Rehabilitation R&D Center and at the 80-bed Spinal Cord Injury Center itself. This arrangement facilitated and fostered contact, communication, and access between all involved.

Between 1987 and 1989, after the rework of the robot system, we performed clinical studies to verify that the tasks and interface design concepts met with users' expectations for a robot assistant [3], and to build on their feedback.

By 1989, we started field studies in real-life vocational settings, and have gained valuable additional data from these long-term installations on robot task and interface design [4, 5].

In 1991, the Palo Alto VA Rehabilitation R&D Center transferred DeVAR technology to a small company. The VA Rehabilitation Evaluation Unit has purchased two systems to perform formal clinical testing of DeVAR at VA Spinal Cord Injury Centers during 1992.

Our robotics program began a 3-year development project in 1991 to focus on the vocational training needs for individuals whose quadriplegia makes accessing conventional learning materials an impossibility. By concentrating on developing a unified software environment and a complete support environment for vocational and daily-living needs, people with physical disabilities can access the vocational materials effectively and compete equally in the computer-based job market.

OBJECTIVES

Function: Rehabilitation robot systems have as their primary goal the return of lost function for people with physically disabilities. Handicaps result from having no means or inadequate means of performing tasks no longer accessible. DeVAR replaces function, not anatomy, by providing its user with a general-purpose, mechanical, programmable servant. Other robots such as Manus take a different approach: they can be seen more as physical extensions of the user [6].

Tasks: DeVAR's design gives it a large repertoire of well-defined tasks in a workstation environment. The tasks involve objects up to 1 kg, and less than 100 mm in at least one dimension. Equipment it can operate must have knobs and handles of good ergonomic design. Some tasks require special fixtures, such as holders for styrofoam cups or racks to hold spoons with medication. In general, normal office and home equipment, objects and actions can be accommodated.

Task Programming: A robot programmer must set up tasks on DeVAR prior to their use. The relationships between interface aspects (voice messages, prompts, warnings), robot programming (tight tolerances, way-points, exception handling, singularities in the kinematics) and the task environment (objects, fixtures, electrical connections) make such an endeavor a major undertaking. More importantly, users have expressed that they do not want to become robot programmers; they just want to use the machine. It is much more important to them that the system operate reliably than that they be able to add a task.

Independence: The set of robot tasks must be able to make the user independent of attendant help for an extended period of time. If this can not be assured, then there is no practical advantage to using a robot, since an attendant will need to be available in case of malfunction or for non-robotized tasks [7]. More importantly, the commercial success of a robot system depends on being able to replace attendant care for two to four hour periods. Any R&D project needs to take such real-world forces into account.

User Profile: The target population for DeVAR consists of individuals with quadriplegia resulting from level-C6 or higher spinal-cord injury, with no head-injury involvement [8]. The need for a well-defined target population allows the first generation of machines to have as homogeneous a user group as possible. The interface and robot requirements for users with other conditions are very different. At this point, it is neither desirable nor technologically feasible to make a safe DeVAR-derivative robot system for operators with cognitive, communicative or certain motor impairments.

Project Goal: To make an effective design, you have to know your user. We have concentrated on making the robot operator our 'user'. In the R&D phase, that is most important. But there are other users. Administrators and health care reimbursement agencies are users of technology as well. They use it to reduce costs and/or improve health care. As systems such as DeVAR enter the marketplace, these users must see the value of their investment. Ease of use (for them!), reliability, maintainability, and customizability acquire new hues.

## APPROACH

The Setting: The primary application of DeVAR is to support the manipulation and environmental control needs of a person with quadriplegia. The focus is on the vocational setting. The primary incentive is to support people who wish to pursue a career, but who cannot do so due to a disability. The goal is to provide independence and privacy by replacing attendant care in the workplace for extended periods of time. The attendant provides set-up, lunch, and evening care, but is otherwise absent. The goal of robot care is to provide an island of independence during a phase of daily life that is most easily aided by automation: the vocational desktop setting.

Role of Attendant Care: A reason for concentrating on the work setting is the unequivocal need for attendant care in the home. It is more difficult to justify a DeVAR-type robot in a home setting due to the natural lack of structure, the need to perform tasks in a space much larger and more varied than a workstation, the need to rely on attendant/family care for many feeding, dressing, and toileting tasks, and the natural companionship of family.

Effectiveness: To ascertain the appropriateness of prescribing a robot system, any potential client receives a preliminary workplace task assessment [8]. An analysis of the tasks then shows whether the robot will be able to attend to all of the on-call vocational and daily-living needs [9]. All tasks that cannot be robotized must be solved in another way. Either the task must be done by the attendant during set-up phases, or other office workers must be able to perform the necessary on-call functions. If the task assessment does not lead to a satisfactory solution, then the decision to install a robot must be reviewed.

Relationship between User and Robot: The DeVAR system is not considered a prosthesis. Rather, the user considers it a mechanical attendant. The user has a very different relationship with DeVAR than with a robot such as Manus [6]. DeVAR is primarily commanded (by voice); Manus is controlled (typically by joystick and buttons), and is therefore much more appropriate for unstructured tasks. Manus, mounted on the wheelchair, goes where the user does. DeVAR, since it is customized to a setting and a task set, is more efficient for the workstation environment. The type of tasks a user needs to do determines which robot geometry and interface are most suitable.

## DISCUSSION AND FUTURE

Workstations such as DeVAR have the advantage of a structured, well-defined domain. Current technology makes robot-based solutions satisfactory from a human perspective, in terms of reliability, speed, ease of use, etc. In larger and unstructured domains, however, much more built-in sensing and computing power are needed to make the systems function reliably and safely. This is not available, even piecemeal, outside of the R&D labs today.

Projecting further into the future, it will require even more computer power, research time, and designer ingenuity to solve the problem of user access to such complex machines. Without an appropriate user interface, only robot programmers will be able to enjoy such robots. It will certainly not be the people whose only goal, vis-à-vis the robot, is to use it to perform tasks that must be done in the normal course of a day. It is a daunting endeavor.

But the future of telerobotics, of which rehabilitation robotics is a small branch for the time being, has much mainstream promise in the coming decades, and people with disabilities will be among its major beneficiaries.

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## ADDRESS

H.F. Machiel Van der Loos
Rehabilitation R&D Center
Veterans Affairs Medical Ctr.
3801 Miranda Ave. #153
Palo Alto, CA 94304-1200

Office: 415-493-5000 #5971
Fax: 415-493-4919
Email: vdl@sunrise.stanford.edu

## MASTER TECHNICAL EVALUATION IN REHABILITATION CENTERS

Jean-Marie Detriché & Bernard Lesigne
French Atomic Energy Commission / DTA/Robotic Unit
Fontenay-aux-Roses, France

### ABSTRACT

This paper presents the results of the technical aspects of the evaluation and the optimization process engaged following the remarks, criticisms and advices coming from the occupational therapists and the users of the MASTER robotized system developed by the French Atomic Energy Commission (CEA).

### BACKGROUND

The MASTER robotized system is a technical aid for helping the seriously disabled of the upper limbs to manipulate objects, including an environmental control system. Several papers have been already published about MASTER (1) (2) (3) (4) (5) and its application within a workstation (6).

Since the begining of 1991, three prototypes of MASTER have been evaluated in the french rehabilitation centers of KERPAPE (Lorient, referred "KE") , LAY ST CHRISTOPHE (Nancy, referred "LS") and L'HOSPITALET (Montoire-sur-le-Loir, referred "HO") . This experience over a period of one year was supervised by INSERM[1] in cooperation with CTNERHI[2]. It has allowed to test to what extent the system is adequate in performing the tasks which were selected for their generic aspect. It has also contributed to evaluate the psycho-sociological impact of such a technical aid on the disabled consumers.

### OBJECTIVE

Two weeks of training to configure, to program and to use the system were assured in the CEA laboratory for the personel of the rehabilitation centers.

The three experimentation sites mentionned beforehand have been selected because they had a suitable technical infrastructure able to easily communicate with the CEA team and because their disabled patients, although similar as concerns their deficiency , implicated different situations.

Indeed, it was essential to ensure the success of the evaluation of such an innovating technical aid like MASTER to cover, as much as possible, a wide range of applications in real situation, from the daily training in a classical occupational therapy department until the home situation. It is the reason why different philosophy were adopted depending on the site, but in any case the users had vountarily accept to participate to this experimentation .So, in some cases the experimentation was conducted during a period spent at the hospital with frequent runs ; the robot being installed in an electronic laboratory (KE) or occupational department (LS) or in the own bedroom for a defined period (HO) .

We shall point out that during or after the experimentation duration some modifications of situation have been done, for example the robot of KE, initially installed in the electronic laboratory has been mounted on a mobile structure and moved in different bedrooms, the robot of HO is now in the public cafeteria of the center, the robot of LS will be transferred at home .

### METHODOLOGY

In each site the fundamental following rules were applied:

- to get a global view of the user's reaction by analyzing their wishes and needs;
- to develop the tasks the users want to be performed in knowing, so far, the limits of the system;
- to test and adapt the user interfaces as regards the nature of the handicap;
- to study the psyco-sociological impact of such sophisticated technical aid in function of the sex, the age, the profession, the time when the handicap occured,etc.; this was realized in answering a questionnaire which was identical for each site and computerized afterwards.

*Evaluation protocole* : Whereas a great autonomy was left to each responsible, a common protocole was adopted as follows:

[1] INSERM : Institut National de la Santé et de la Recherche Medicale

[2] CTNRHI : Centre Technique Nationale de Recherche sur le handicap et les Inadaptations

- To present the whole system;
- To try the different user interfaces depending of the user's handicap;
- To show the different automatic tasks;
- To show the functioning in direct mode.

The training time was variable depending on the availability of the patients sometimes half a day , sometimes a week, the mean time being 12 hours .

*Population characteristics* : Generally, the studied cases mainly concerned the functional quadriplegia· spinal injured with high level and muscular distrophy patients. For the cerebral palsy individuals, it has been frequently necessary to give a personal touch to the user interface. Some arthrogriposis and S.E. P. patients have also participated to this experimentation.
A majority of men have participated to these evaluations, they are generally young , the level of study is variable, they live now at home, their handicap is not recent and their residual motricity is quite limited. They use an electronic wheelchair and demand that the user interface used to command the robot was compatible with it.

*Tasks realized:* In the three sites, the following tasks have been tested and validated : DRINK, PHONE and AUDIO/ VIDEO. They employ automatic programs written with the MASTER language and for the two last they make a call to the direct mode and the environmental control system. In addition, many programs have been written by the occupational therapists, bringing a typewriter, fetching a board, ,turning pages of a magazine, eating ,smoking,playing othello and chess, toilet : shaving,washing,wiping,etc..

*Wanted improvements :* All users want some improvements in the man-machine dialogue and chiefly a more efficient speech recognition unit, a digital voice to confirm orders, a cordless link between the robot and the user. The arrangement of robot within the workstation need further upgrades and it is wished that the robot was installed on a mobile base.

## DESIGN CONCEPT

Taking into consideration all comments and criticisms hereabove ,the CEA started at the begining of 1992 the study and development of a new version of the MASTER system still always limited to a fixed manipulator.

Considering the architecture of the system, we are undertaking the control of the whole functionalities of the system from a personal computer. Thus, the robot controller, the environmental control system, the man-machine interface and the office softwares daily employed by the disabled persons are designed in an integral way. This permits the integration of computized office work in the system. The cumbersomeness, the number of connecting interfaces is obviously reduced, thus increasing the reliability of the system. The use of standard commercially available hardware give rise, so far, to a reduction of the final cost.
Taking into consideration the priority access to some functions, as alarm, telephone...the environmental control system becomes the basic unit of the system, the manipulator remaining a sophisticated peripheral, the man-machine communication will be easier to use thanks to a new pictographic presentation on a larger video display and a more efficient speech recognition unit. To realize automatic tasks two programming levels will be available: a user-friendly task oriented language accessible to non-specialist users, linked with a data base describing the objects to be manipulated by the robot within the workstation, and an off-line programming language for more complex tasks. This will allow to create more interactive programs and make easier the use of the complete robotized system with a better safety.
This improvements will be evaluated on an office workstation at the end of 1992, at the home of a CEA's tetraplegic engineer.

## AKNOWLEGMENTS

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Jean-Marie DETRICHE
CEA/CEN FAR/DTA/Unité Robotique
Bat. 38
B.P. 6
92265 Fontenay-aux-Roses Cedex - France
Tel : 33 - 1- 46 54 91 18
Fax: 33 - 1- 46 54 02 36

# Research in Interactive Robotics in the Cambridge University Department of Engineering

R D Jackson, R M Mahoney and J L Dallaway,
Cambridge University Department of Engineering,
G Dargie, Papworth Group, Cambridge

## 1. Introduction

Research at Cambridge into interactive robotics for applications in rehabilitation has concentrated on the development of the task-level programming language CURL and certain aspects of the human-computer interface. The research programme has been supported by extensive user trials which fall under two main headings; educational tasks and vocational tasks. The user trials to date have made use of the RTX robot, but a current project includes the development of a special-purpose robot for a range of inspection tasks within industry.

The interface to CURL is discussed later in this paper. The next sections outline the tasks which users have been able to carry out using a robot system. The activities covered by the research programme started with classroom-based educational tasks and then moved to vocational activities. The vocational activities have been concerned with inspection tasks within light assembly and the electronics industry.

## 2. Activities and their user groups

### 2.1 Educational activities

This research programme [1] was aimed specifically at providing assistance in the developmental education of physically disabled children. The programme was carried out with the Barnardos New Mossford School in North London between about 1986 and 1989. The children who used the robot were wheelchair users and mainly lacked the manual dexterity to manipulate objects. Many had also suffered some degree of brain damage. The children ranged in age from 3 to 18.

The main activities for which robot-assisted schemes were devised were:

- Early developmental education activities
- Interactive game play
- Painting
- Interactive chemistry experiments
- Elementary cooking
- Robot-assisted feeding

In planning the tasks the role of the teacher was regarded as essential. The teacher sets up the activity, with the robot actions programmed using CURL. It should be noted that CURL has been designed to be accessible at the programming level to people who are not expert computer users. The teacher also acts as supervisor during the activity, as in most classroom activities.

### 2.2 Vocational assessment activities

An assessment procedure is important when introducing a robot system to a particular disabled individual and there must exist some formal method for measuring a person's ability to use the robot effectively.

Within the research programme assessment has been largely the responsibility of the Papworth Group. The Group is collaborating with the Cambridge Engineering Department in a project supported by the ACME Directorate of the UK Science and Engineering Research Council [2]. The Papworth Group contains vocational placement specialists who are concerned with assessment and placement of people with physical disabilities.

The initial assessment task used one of the VALPAR Tri-level Measurement Worksamples. This worksample measures a persons ability to perform precise inspection and measurement tasks and to make decisions based on certain criteria. In its basic form it requires visual acuity, discrimination, decision-making, forward reach and hand-eye coordination. A robot-assisted version of the worksample has been set up which allows a disabled person to inspect the workpieces, make the appropriate decisions and instruct a robot to carry out the required manipulation.

The VALPAR task does not offer a means of providing a standard test for assessing user-robot interaction. A second assessment system is now being developed at Papworth and has been given the acronym IRQAT [3] (Interactive Robot Quantitative Assessment Test). Its main purpose is to provide a measure of an individual's ability to control a robot whilst performing a generic task using a range of control approaches. It consists of a set of pegs which have to be moved over a barrier and placed in holes in a rack.

The IRQAT will use the full features of the current version of CURL, including the log facility to record time taken and commands used. IRQAT uses a number of levels of interaction. The first level is purely passive as far as the user is concerned. Whilst the robot is doing the task on this automated level, the user is being instructed as to the functions the robot is performing. The instructions will be in the form of a standard script. This stage gives the user an understanding of the task and a view of the motions it can perform. It also allows the base time for the task to be established.

On the second level, the user is given access to a Procedure Selection Menu which offers a number of procedures to complete the task. The time the user takes to do this is stored.

On the third level, the user is given access to a Command Selection Menu from which a number of lower level procedures can be selected to complete the task.

On the fourth trial, the user is given access to a Direct Drive Menu which allows direct control of the robot's movements. The time for this is also taken.

The initial aim is to assess a group of employees of the Papworth Group, each with a different level of motor dysfunction. They will complete the various levels of the task and attempt different control approaches. The results will be analysed and a norm group will be established for the future comparison of people using the system. The long term aim is to be able to include the IRQAT as part of a standard vocational assessment as already performed at the Assessment and Development Centre of Papworth. People identified as having appropriate reasoning ability, plus limited motor skills, will be assessed as to their ability to use a generic interactive robot environment.

### 2.3 Workshop activities

The choice of an inspection task as most suitable for the initial implementation of a vocational workstation was made following detailed consideration of the opportunities for interactive robotics within manufacturing industry [4]. The key to success in the choice of task is the identification of an activity in which the introduction of interactive robotic methods can improve the overall production process. The following criteria for task selection are proposed:

-The chosen task must be within the manufacturing industry and require human decision making and modest manual dexterity.
-The task must have a high decision-making to manipulation requirement.
-The semi-automation of the task must provide a benefit to the target industries.
-The introduction of automation will not eliminate the need for human decision-making.

-The disabled individual should be able to interact with the robot in order to perform the task with minimal assistance from fellow employees.
-The introduction of the robot hardware should involve minimum disturbance to the existing industrial practice and plant set-up.

A workstation which satisfies these criteria is under development in a collaborative exercise involving Cambridge, the Papworth Group and Graseby Microsystems. It is intended for the visual inspection of hybrid microcircuits, and has been given the acronym IRVIS (Interactive robot visual inspection system). Its main component is an interactive camera manipulation and circuit handling system. IRVIS will be designed to provide additional functionality so that the user can carry out all aspects of the task of visual inspection:

-Automated movement of microcircuits during inspection.
-Automated control of camera inspection equipment.
-Computer-based document storage and retrieval.
-Computer-based access to pictures and diagrams for reference.
-Document preparation and updating.

### 3. Human-computer interface

The initial versions of CURL, which were developed for the educational activities, operate under MSDOS [5]. Where necessary, they use screen text display as feedback to the user. The user input method was usually chosen to be the same as that used by the children for access to other aids within the classroom. Input devices ranging from a single switch to a full keyboard were used.

Many of the tasks used a sound prompt from the computer and no feedback from a visual display. In this way they offered more direct interaction between robot and user. For example, in a block colour matching test the robot picks up a coloured block and holds it over a bin while prompting the user. The user can accept or reject the robot's offer to drop the block into the bin.

All task procedures programmed in CURL are accessible via the computer display using two independent binary inputs, one to scan and the second to select. In general, the educational tasks were devised so that they did not require the direct drive mode within CURL and proportional analogue input was not needed.

The full functionality of CURL requires the equivalent of a two-dimensional joystick and two switches. The current MSDOS version of the program allows the use of a standard commercial joystick, connected via the games port, with menu options specific to the joystick displayed on the computer screen. It is anticipated that most users of interactive robotics within industry will use a wheelchair for mobility and a joystick or equivalent is envisaged as the main means of input for the interactive workstation now being developed.

Some tests have been carried out using voice input. Voice input has the advantage that it offers a direct method for accessing computers for people unable to use a normal keyboard. The user is able to maintain his or her attention on the activity rather than the interface device. The use of speech feedback again removes a source of distraction between user and robot.

A version of CURL which operates under the Windows environment is in preparation. This version should offer considerable improvements in the human-computer interface. It is proposed that each functional component of CURL should exist in a separate window. Any combination of the CURL functions may therefore be viewed and accessed at the same time. The use of the Windows Visual Keyboard (WiViK) will facilitate access to CURL and other programs running under Windows for non-keyboard users. WiViK provides keyboard emulation when the user clicks on the 'keys' using a mouse or mouse emulator.

## 4. Current research

As described in the previous section, work on the porting of the CURL program to the Windows environment is now in progress. Access to Windows by people with physical disability has recently been improved through both software and hardware developments. Examples are the keyboard emulator controlled by mouse equivalents based on trackerballs and joysticks. Another advantage of the move to Windows is that access to CURL can be provided in a standard form for applications in which the control of a robotic device forms only part of the functions implemented on the controlling computer.

CURL was designed to facilitate the rapid interfacing of new devices. However, the only robot drivers currently implemented are for the UMI RT series robot arms. An interfacing specification is under development to formalise the communication requirements between CURL and a generic device. This specification should provide a framework for the development of new CURL device drivers within the Windows version.

The use of sensors and the incorporation of feedback from sensors within the control loop are also under active consideration. The feedback may be used to augment the operator's understanding of the environment or to modify the information in the CURL database of objects. Some work is in progress on a computer vision system which extends earlier work [1] on the use of markers to identify objects to be picked up by the robot.

## 5. Conclusions

The research programme in rehabilitation robotics at Cambridge has included a number of user trials at the Barnardos New Mossford School and the Papworth Group. The work with the Papworth Group has led to a new approach to quantitative assessment of the way in which a user can use a robot system to carry out certain manipulative tasks.

A collaborative programme with the Papworth Group and Graseby Microsystems has as its objective the development of a workstation which will enable a person with severe disability to undertake an inspection task within a production process.

## 6. Acknowledgements

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For further information, contact:
R.D. Jackson
Department of Engineering
University of Cambridge
Trumpington Street
Cambridge, England
CB2 1PZ
phone: (0223) 332690
fax: (0223) 332662
email: rdj1@cam.eng.ac.uk

## WORKPLACES WITH ROBOTS FOR PEOPLE WITH PHYSICAL DISABILITY AN EXPERIMENT

Willem van Dort
Institute for Rehabilitation Research (IRV), Hoensbroek
The Netherlands

### Introduction

Jobs for poeple with motor handicaps are very scarce. Persons with a reasonable education and work experience have the best opportunities to keep their job or to find a new job, specially when they acquired a disability as a result of an accident. But it is very difficult for them too. The Dutch Government announced in 1988 regulations to force the industry to employ handicapped people. The industry does not like to employ handicapped people since their production can be substantially lower and is thus more costly than that of non-handicapped workers.

In spite of the progressive character of these regulations, the Dutch Government was not able to supply the industry with guidelines for the kind of workplace, type of work, tools etc., simply due to lack of information about this subject. Workstations with vocational robotic arms designed for specific persons and for specific tasks have shown that small size robotic arms can help people to perform a task. However, the experiences with these workstations, although all being very positive, are such that they cannot be used as general guidelines.

It is from this background and under the assumption that in metal and electronic industries small and medium size robotic manipulators will be used on a large scale for the assembly of parts and the fabrication of components that this experiment in a sheltered workshop was carried out.

### Statement of Problem

In general, performing a task requiring motor skills, a worker with a motor handicap will need some assistive tools and will develop specific strategies to compensate for limitations of his/her motor functions. Under the assumption that a multi-functional robotic arm can be used as an assistive tool to the worker, a task can be divided into sub-tasks in such a way that the worker can perform some sub-tasks and the robotic arm can do the remaining sub-tasks. The activities of the robotic arm can vary from passing tools and components to the worker, to a fully automated tool requiring no human intervention. The worker can also act as a supervisor or can index the robotic arm.

The primary goal of this experiment was to identify a method that allows for an objective division of a task into sub-tasks to be performed by the worker with limited arm and/or hand functions, and into sub-tasks for the robot. Other objectives were to demonstrate the method with a real industrial task in a real production environment and to identify guidelines for the human interface with the robot.

To create a job, economical and social aspects have to be taken into account. These aspects will not be considered, in spite of the fact that a job cannot be done if e.g. no transportation is available.

### Method

Since the potential group of workers are people with limited or no motor function, a description of a task in terms of sensori-motor activities of a human being is required. Traditional methods for task analysis cannot be used, since they are mainly based on performance, thus measuring experience; such as, how fast can a person drill holes or put components together.

A comparison of the sensori-motor activities required by the actual task with those of the worker, identifies basically the task activities the worker can perform and consequently also the sub-tasks for the robot.

The Method Time Measurement (MTM) is a method for analyzing tasks based on the fact that a task is actually a sequence of elementary motions of the human being performing that task. For example to grasp a pencil from the table, one has first to reach for it, then grasp the pencil, lift it, and finally to reposition the hand to the desired position: four elementary motions. MTM distinguishes 20 elementary motions.

Another characteristic of MTM is that, weighted by the difficulty of the motion, each elementary motion has been given an amount of time, the normalized execution time. The nominal execution time for a given task can be calculated by simply adding the individual normalized execution times of all identified elementary motions.

MTM allows also for a number of other aspects:

- The individuals performance, related to his/her own work method, can be calculated by comparing the measured task time with the nominal execution time;
- MTM allows to identify the strategy for compensation for limited motor functions by comparing the MTM analysis of a task performed by a worker with limited motor functions with that of the same task done by an able-bodied person.

Since the method is based on elementary movements, it can be used for the analysis of any task performed by anybody including robots. This may result into some guidelines for the human interface and the control program for the robot and the calculation of the robot performance.

The execution of a complete task is a combination of human and of robotic activities. Synchronization is therefore very important. Guidelines for synchronization can be found in the MTM analysis.

The MAST test can be used for the assessment of the worker, the inventory of motor functions. This assessment test is based on MTM and tests each elementary movement and combinations of motions in an increasing order of difficulty. The result of the assessment shows which motor functions are available and what type of job activity the individual can do best, e.g. surface mounting.

The Purdue Pegboard Test or the Minnesota Manual Dexterity Test, used for therapeutic purposes, are not capable of analyzing the person's motor function in sufficient detail.

The experiment was carried out in a sheltered workshop. This is an ideal situation because:

- the work environment of the workshop is adapted and accessible for handicapped people; and not only for motorically handicapped persons;
- the staff is well trained and familiar with workers with disabilities;
- most of the workers have disabilities;
- it is a real production environment with real tasks which are subjected to quality and production standards;
- to isolate the test results from "noise".

The experiment was an assembly task where mounting clamps for central heating water supply pipes were assembled by a worker who was functionally one-handed and had limited motor function. These clamps are regular products ordered by clients who have alternative suppliers. This assembly task could be done by the worker, however with difficulties. This allowed the identification of a strategy for compensation. The robotic arm used was a UMI-RTX.

It should be taken into account that manual work can be a form of training, of physical therapy. For example persons with atrophy have to keep their muscles going to prevent loss of their use. It was for this reason that it was decided to let the robot give only the minimal assistance during the experiment.

Handicapped people are more vulnerable than able-bodied persons in the case of calamities. Using a robot as an assistive tool requires people to be within or very close to the robots envelop of movement. Therefore, this aspect is very important within the process of decision for the actual task decomposition.

**Results**

Without going into details, the most significant results will be presented. The experiment showed that the MTM for task analysis and the MAST for the assessment are valuable instruments to indicate where and when robotic assistance is required. A negative aspect is that both methods require trained analysts.

For the actual division of a task into sub-tasks aspects such as safety, medical or therapeutic reasons have to be taken into account.

The first check should be this one: can the robot perform its share of the task. For example, it can be too complex or there is no physical space for the robot to move its arm, etc.

With the MTM method it could be shown that a robot can be a useful assistive tool. An increase of production of more than 10 percent was realized by the test person, although this was not foreseen and was not a goal of this experiment.

With respect to the user interface, it was found that object oriented control, where the user interacts with the robot instead of with the computer, was the best strategy in this environment. We also found that the input device should fit in the work environment and that it should also be adapted to the workers capabilities. Therefore a single switch was used instead of a keyboard.

If the worker has sufficient responsibility and mental skills for his work, it is recommended to have the worker supervise the robot. It gives the individual the feeling to be independent since he is in control. It is also a safe method, specially when the robot automatically halts somewhere during the execution of the task to synchronise and in this way to allow the worker to check the robots functioning.

Being based on a single experiment, the results can only be used as indicators for guidelines and much more experiments are required. Those experiments should also include logistics, since it was found that problems with the execution of a task tend to turn into logistic problems requiring solutions that may be more complex and more expensive than the solution of the original problem.

Author's Address
Mr. Willem van Dort
Institute for Rehabilitation Research (IRV)
111 Zandbersweg
6432 CC Hoensbroek
The Netherlands

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# Technology in Poorer Countries and the Wider Impact of Solutions on Specific Problems

# MEASURING SUCCESS IN THIRD WORLD WHEELCHAIR BUILDING

Ralf D. Hotchkiss & Peter Pfaelzer
Wheeled Mobility Center, San Francisco State University

## ABSTRACT

The wheelchair industry in developing nations is growing rapidly. As the growth of new projects gains momentum, the need to analyze the success of the most effective manufacturers becomes clear. This analysis must be shared with wheelchair enterprises across the globe, and with others, like ourselves, who are involved in technology transfer activities. In this paper we suggest some characteristics common to successful shops. We also present a comprehensive model for technology transfer for wheelchair building in developing nations.

## THE PROBLEM

For at least 20 million people in developing countries, the disability rights movement is but a dim fantasy. Many would struggle for education, jobs, and self determination, except for one critical obstacle: they have no way to move from place to place. It is clear that human beings who can't use their legs need a set of wheels. However, most of the world's people who need a wheelchair, currently have little likelihood of getting one in their lifetime.

## HISTORY OF THE PROJECT

A program of wheelchair building in developing nations has been going on for the past twelve years. We have worked with wheelchair builders in a variety of countries to develop an indigenously manufactured, lightweight, semi-sports model chair--the Torbellino (Spanish for "whirlwind"). In the last twelve years, twenty-five small-scale manufacturing shops have been established in 20 different countries. Over 150 mechanics have been trained. This pilot project has produced several thousand wheelchairs, and has demonstrated the viability of small shop production in developing nations.

## TECHNICAL TRANSFER MODEL

Our technology transfer model - small scale enterprises in which wheelchair riders produce chairs using local materials - is based on several considerations. First, in most countries, local production can provide wheelchairs at significantly lower costs than importing chairs. Second, when locally made chairs break, they can be quickly repaired without the need for importing expensive spare parts. Third, the general metal-working and manufacturing skills associated with wheelchair manufacturing provide an excellent vocational opportunity for wheelchair riders. Finally, and perhaps most importantly, riders have a strong motivation to continually improve the design and quality of the wheelchairs they produce. Better chairs enhance their independence. A continuous stream of improved wheelchair designs has been the result of this approach.

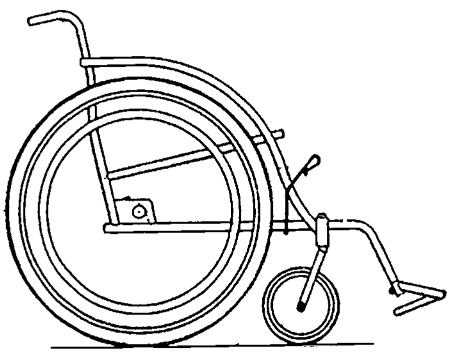
## MEASURING SUCCESS

The wheelchair industry in developing nations is growing rapidly. Over the past twelve years, working with wheelchair builders in developing nations, we have observed some projects succeed while others fail. As the growth of new projects gains momentum, the need to analyze the success of the most effective manufacturers becomes clear. Numerous potential wheelchair builders have asked what makes some factories thrive while others do poorly. People with disabilities have asked for help to raise the quality of work of their local manufacturers, some of whom are making shoddy or overpriced wheelchairs. We define success as the ability to produce large volumes of high quality chairs that are low in price, durable in the field, and that promote independence among wheelchair riders. The following characteristics are common to successful shops:

Quality chairs
Quality chairs are well designed. Put quite simply, they work. Their design fits both the population and the environment for which they were intended. Quality chairs are dependable. Good design, fabrication and quality control enables quality chairs to be utilized in the rough urban and rural conditions encountered in developing nations. The mean-time-to- failure for wheelchairs in developing nations is no less than that of chairs used in the industrialized countries. All wheelchairs break down. Quality chairs are repairable. This generally means that parts are designed to be repaired by local craftspeople, rather than replaced. Spare parts are usually unavailable, and/or costly in developing nations.

BUILDING WHEELCHAIRS • CREATING OPPORTUNITIES

## The Torbellino II: Preparing for the 21st Century



Narrow elevator doors in Siberia, Centralized manufacture in India with a "one size fits all" mentality, the need for better sports chairs in Nicaragua, the extreme cost of bearings in Peru, the need for childrens' chairs in Sri Lanka - all have required the development of a new type of multi-purpose chair. After 7 years of design and testing, our network of wheelchair rider-builders is ready to begin the disemmination of the Torbellino II. Its new features include:

- o **Self-Narrowing** - adapted from the <u>Altimate</u> patent - so the rider can squeeze through narrow doors
- o **Adjustible Width** - the rider has the choice of 5 seat widths in a single chair
- o **Adjustable Axle Position** - with choice of 8 positions
- o **Sealed Needle Bearings** - made of nails/coat hangers
- o **Radical Footrest Adjustment** - 8" (20 cm) vert. motion
- o **The Zimbabwe Wheel** - The ride and flotation of a wide front pneumatic with no flats, at very low cost
- o **Camber adjustment** - seperate wheel <u>and</u> sideframe camber adjustments, for custom backrest fitting

<u>Affordable chairs</u>
A successful wheelchair shop not only produces quality chairs, but also sells them. Cost control is the key to keeping the price low. Materials utilized in production are locally available and relatively inexpensive. Batch processing of parts is used to keep labor costs to a minimum. Overhead or fixed costs are controlled and included in the purchase price of the chair. Even with attention to all these details, the purchase price of a wheelchair may be excessive for a person with a disability. In some cases, the manufacturers have cooperated with other organizations or banks to develop innovative financing schemes. Revolving loan funds to consumers have been utilized successfully in Columbia to enable poorer persons with disabilities to purchase a chair. To help the maximum number of people buy wheelchairs, the group in the Philippines uses donated funds to give <u>partial</u> subsidies. Successful wheelchair shops are as skilled in meeting the financial challenges of wheelchair production as they are in solving their technical problems.

<u>Consumer involvement</u>
Active consumer involvement in production has been vital to the most successful wheelchair enterprises. Chair design and durability must be evaluated by experienced riders who understand the production process. Persons with disabilities have a strong vested interest in producing a quality product and running a successful business. Disability movements in developing nations also benefit from consumer involvement in production. As employees persons with disabilities serve as role models. They inspire their peers to fight for the jobs they deserve. A self-help, or independent living model for persons with disabilities can replace the charity model which is prevalent in developing nations. Furthermore, as a large number of consumers become mobilized, and enter a variety of occupations, capital can be infused into the local disability movement.

<u>Quantity of chairs</u>
To be successful, a wheelchair shop must operate efficiently. The production capability of individual shops varies greatly depending on the initial capital investment and the production model which is utilized. Small scale, low capital, labor intensive production is appropriate in countries with low labor rates. Even if it takes a week for a person to make a chair, the labor cost is still not a large percent of the chair's total cost. In areas with larger markets to be served, medium scale production requires more sophisticated planning and management as well as more investment in tools and fixtures. All wheelchair components must be standardized and interchangeable for medium scale production.

## A GLOBAL APPROACH

In a paper presented at the 1990 RESNA Annual Conference entitled "Third World Wheelchair Manufacture: Will It Ever Meet the Need?", we estimated that 20,000,000 wheelchairs were currently needed in developing nations. While our 12 year pilot project has been successful by many measures, only five to ten thousand wheelchairs have been produced by shops with which we've worked. Clearly, a bolder, more comprehensive, long term, global plan must be developed.

Mr. Henry Hof, a senior economic affairs officer in the United Nations' Department of Economic and Social Development and a wheelchair rider himself, is coordinating a committee which is designing a global plan. Central to this plan is a substantial increase in the current growth rate of wheelchair production in developing nations. The long term goal of producing and distributing tens of millions of wheelchairs in developing nations, if it is successful, will take 20 to 30 years.

The goal for the initial three year phase of the project is to develop an infrastructure in several marketing regions in different parts of the world. A measurable goal three year project is a significant increase in the current growth-rate of wheelchair production in each region. The plan specifies the initiation of small scale enterprises which will employ men and women, including those with disabilities, in meaningful and productive positions of responsibility.

The global plan envisions a network of regional resource and training centers throughout the world. These centers will be responsible for providing assistance to both new and existing wheelchair manufacturers in their regions. A Program Support Group (PSG) will be available to assist the regional resource and training centers as well as local producers.

## THE PROGRAM SUPPORT GROUP

The Program Support Group will assist with:

* Statistical information on the need for wheelchairs in specific countries.
* Capitalization of small shops and larger factories.
* Training of wheelchair builders.
* Creating financing plans for consumers.
* Training of rehabilitation professionals.
* The promotion of mobility and independence for persons with disabilities in developing countries.
* On going evaluation and refinement of the regional and local projects.

The Program Support Group will provide governments and organizations in developing nations with a single comprehensive package to carry out both economic and social development. The United Nations' Department of Economic and Social Development, working with UNDP, ILO, and UNIDO, will be responsible for directing the activities of the PSG. The PSG will assist local executing and cooperating agencies during the infrastructure development period. The PSG will also be responsible for global coordination of the project. After final approval by the boards of the respective organizations, the roles they will assume within the PSG include:

- For Technical Assistance and Training: The **Wheeled Mobility Center**, San Francisco State University, San Francisco, California
- For Business Assistance: **Appropriate Technology International (ATI)**, Washington, D.C.
- For Consumer Financial Assistance: **Appropriate Technology International (ATI)**, Washington, D.C.
- For Advocacy Assistance: **Rehabilitation International**, New York, New York; and **Disabled People International**, Winnipeg, Manitoba
- For Statistics and Evaluation: **United Nations Statistical Office**, DESD, New York

## MODEL FOR PROJECT IMPLEMENTATION

Implementation of the project reflects the United Nations' new emphasis on local execution. Government ministries, in association with interested local non-governmental organizations, will be the executing and cooperating agencies in each country. The participation of local organizations of persons with disabilities will be required. In each country, local nationals will have ultimate responsibility for the project. Collaborating local agencies will work with the previously described Program Support Group to realize the project goals in their particular countries. The project will seek local and international funds to support activities in each country.

Full approval and funding for the overall plan is targeted for mid-1992. If you would like to explore the possibility of securing support for wheelchair building in your country, contact:

Mr. Henry Hof
Department of Economic and Social Development
United Nations
New York, NY 10017, USA
Phone: (212) 963-7168

or

Ralf Hotchkiss & Peter Pfaelzer
Division of Engineering
San Francisco State University
1600 Holloway Avenue
San Francisco, CA 94132, USA
Phone: (415) 338-2878

# ANSI/RESNA Wheelchair Standards Committee Presentations

## Dynamic Structural Response of a Cross-Tube Wheelchair Frame

J.D. Baldwin, L.S. Dee and J.G. Thacker
University of Virginia Rehabilitation Engineering Center
Charlottesville, VA 22903

### Introduction

Testing is currently underway to determine the nature of the structural deformations experienced by a loaded wheelchair. In this case, the deformations are the strains experienced by a cross tube in a folding design wheelchair. Experimental determination of these deformations is the first step toward a metal fatigue analysis of the structure. The various theories of metal fatigue require that the analyst know either the strain or stress history of the structural element under load (stresses can be derived from strain data).

Previous efforts [1] have focused on the computational aspects of the wheelchair fatigue/reliability problem, but they have used assumed stress/strain histories instead of actual data. This investigation is being undertaken to provide the necessary structural response data to perform the wheelchair fatigue/reliability calculations.

### Background

Active wheelchair users operate their wheelchairs over many different terrains in the course of their day. The roughness of the terrain and a particular wheelchair structure's response to that terrain are the controlling factors in several aspects of wheelchair performance including ride comfort and the long-term survivability of the structure. Long-term survivability, or reliability, of the wheelchair frame is basically an issue of the frame's susceptibility to metal fatigue and the accumulation of fatigue damage over the lifetime of the wheelchair.

The probability of fatigue failure of a tubular wheelchair frame has been addressed [1], but purely from the perspective of assumed structural loading. That is, the analyst was presumed to have structural load and response data for the wheelchair frame under consideration. At the time no real data for the response of a wheelchair structure under load was available.

### Testing Procedures

The current research undertakes to test wheelchairs under various dynamic loadings and measure the pertinent structural response parameters with the intention of eventually incorporating the findings into a wheelchair structural reliability model. In particular, two wheelchairs, one manual and one powered, have been instrumented with electrical resistance strain gages. Both wheelchairs are of the folding type with two cross tubes pinned together at the center. The strain gages are connected to a computerized data acquisition system which allows high speed data acquisition and data storage.

To date, only the manual wheelchair has undergone any testing. That wheelchair has been tested on a treadmill with two different "bumps" attached. Wooden dowels across the treadmill belt served as bumps.

The wheelchairs were instrumented with three element rectangular strain gage rosettes, shown in Figure 1. Each of the three arms of the rosette is an active strain gage. By using rosettes such as these, we can calculate the principal strains and their directions very easily [2]. These strain gages respond to the deformation of the metal they are bonded to by a change in their resistance; the change in resistance is measured as a voltage, $E$, output by an electrical circuit known as the Wheatstone bridge, Figure 2; the voltage $V$ is the bridge supply voltage. The voltage output by the Wheatstone bridge may be transformed mathematically to give the measured strain. The three elements of the rosette have been designated Gage 1, Gage 2 and Gage 3, proceeding counterclockwise from the lower left. Each gage has its own Wheatstone bridge circuit.

Two strain gages were attached to a cross tube, one on the side of the tube directly adjacent to the center pin, the other on the bottom of the tube lying along the pin. The locations of the strain gages are shown in Figure 3. The cross tube was chosen for this initial investigation because several finite element analyses of this type of structure have shown the largest stresses to occur in this area. The strain gage installation is the same on both the manual and power wheelchairs under test. As shown in the figure, the strain gage rosettes have been designated XG1 and XG2.

The strain gages are connected to a bank of strain gage conditioners/signal amplifiers. Each signal conditioner provides the excitation voltage $V$ to the Wheatstone bridge and controls the amplification of the very small voltages output from the bridge.

The amplified voltages pass through a low-pass filter with a signal cutoff at 30 Hz. The low pass filter acts as a frequency limiter, eliminating elements of the dynamic strain signal that have frequencies larger than the cutoff. This effectively eliminates the electrical noise induced by the fluorescent room lighting, nearby power equipment, and miscellaneous atmospheric electrical disturbances. When filtering a signal, one must consider how much data is being thrown away by the filtering process. In this case, unfiltered dynamic strain signals were examined in the frequency domain and it was found that no significant frequency content existed above about 15 Hz. (except a large signal at 60 Hz. attributable to lighting), thus no real data loss occurs due to filtering. It is conceivable, though, that an experimental testing program may excite strains in the wheelchair frame that have higher frequency content, in which case a different filtering strategy must be used.

The filtered strain signals are sampled by a MetraByte DAS16 analogue-to-digital (A/D) data acquisition board mounted in a personal computer. The A/D board is programmed to sample the analogue strain signals (voltages) at predetermined intervals and convert them to digital values suitable for computer storage and manipulation.

A critical issue in sampling dynamic signals is that of selecting an appropriate sampling rate. If the sampling rate is chosen such that a significant amount of signal frequency content occurs above the sampling rate, a phenomenon known as *aliasing* occurs whereby the energy of the higher frequency signals is recorded at lower frequencies. The aliased signals are not a accurate representation of the true signal. This problem is avoided by applying the Nyquist sampling theorem [3] which states that to avoid aliasing, the sampling rate can be no smaller than twice the largest signal frequency.

The low pass filters provide strain signals with a known high frequency content, therefore the sampling can occur at a multiple of this upper frequency. The filters have finite frequency roll off at the upper end and provide full attenuation at about 50 Hz. The Nyquist theorem requires in this case that sampling occur no slower than 100 Hz. To obtain an accurate representation of the signal we oversample this rate and to accommodate other signal processing requirements we collect a number of samples that is an integer power of 2. The sampling rate is set at 512 samples/second for each channel.

## Test Results

A series of tests was carried out on the manual wheelchair rolling on a treadmill with a 177 pound live rider. The strain gage rosettes were oriented as in Figure 3. The test was performed under three terrain conditions: no bump, 0.375 inch diameter bump and 0.625 inch diameter bump. The treadmill speed was nominally 1.0 meters/second. Each data stream consisted of four seconds of sampling (2048 data points) from a single strain gage rosette. Twenty no-bump data sets, thirty 0.375 inch bump data sets and thirty 0.625 inch bump data sets were recorded for each strain gage rosette (XG1 and XG2) for a total of 160 data sets.

The data processing stage of the investigation required that the recorded digital values be converted to voltages and then to strains. The strains were corrected for the transverse sensitivity of the strain gages [4] and then the mean and standard deviation of each strain gage was calculated. Earlier investigations [1] incorporated the assumption that the structural response could be adequately described by a stationary, narrow band Gaussian (Normal) random process. Several statistical tests [3] were performed on each data set to determine the agreement of the measured strains with these assumptions. The Chi-Square goodness of fit test provided an estimate of the agreement between the measured data and a Normal distribution. The Reverse Arrangements test for data independence addresses the stationarity of the data stream; in this case we investigated the stationary nature of the data's mean square value. Finally, the regularity factor [5] of the data stream was calculated to determine whether the data represented narrow band response. For experimental data the regularity factor is defined as the number of times a data stream has an upcrossing of its mean value divided by the number of peaks above the mean value. The regularity factor can have values in the interval $0 < \alpha$ 1; $\alpha = 0$ indicates wide band response and $\alpha = 1$ indicates narrow band response.

A representative data set will be examined in detail. The data set designated TRD55 is from a four second test on the manual wheelchair, recording strain gage rosette XG1. The treadmill bump was 0.375 inches in diameter and the treadmill speed was 1 meters/second. The strain versus time plot of this test is shown in Figure 4. Note that the time is in digital format with 512 corresponding to 1 second, 1024 corresponding to 2 seconds and so on.

Notice that the strains recorded by gage 1 is nearly always in compression while gage 3 is usually in tension. Gage 2 undergoes both tension and compression in a cyclic fashion. It is also interesting to note that the gage 2 signal has much wider variations over time than either gage 1 or gage 3. This is the result of the orientation of the gage 2 element of the rosette along the tube axis, as shown in Figure 3, tending to measure the overall axial tension and compression of the tube as well as any bending action. The orientations of gages 1 and 3 are such that they tend to measure the torsion of the tube, which the data shows to be a relatively constant state. A very noticeable feature of this data set is the rapid variations shown by all three gages in the time interval 768-1024 (0.75-1.0 seconds). This is the point where the wheelchair responded most vigorously to the bump on the treadmill. It is not clear at this point whether these extreme responses are due to the bump impacting the front or rear wheels of the wheelchair.

The calculated Chi-Square measures [3] for the three strain data streams are 669.4 for gage 1, 341.7 for gage 2 and 2337.3 for gage 3. In order for the data to be presumed to be from a Normal distribution at 95% confidence, the Chi-Square value would be less than 24.7. Clearly, the Normal distribution assumption does not hold for these data. In fact, of the 160 data sets examined so far, none have passed the Chi-Square test. The assumption of a Normal random process is not justified.

The reverse arrangements test [3] of the three data streams yielded 95 reverse arrangements on gage 1, 110 on gage 2 and 68 on gage 3. The 95% confidence interval for the reverse arrangements test is from 65 to 125 reversals; this data set exhibits stationary behavior. Most, but not all, data streams examined so far have passed the stationarity test.

Finally the three strain data regularity factors were found to be 0.096 for gage 1, 0.066 for gage 2 and 0.148 for gage 3. Therefore, like the assumption of Normality, the narrow band assumption does not hold for this data set. These numbers are typical of the other data sets.

## Conclusions

The test program described here has been useful in demonstrating the random nature of the dynamic strains in a wheelchair cross tube. Testing will be expanded to explore the response of the power wheelchair and the effect of different test terrains.

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J.D. Baldwin
University of Virginia Rehabilitation Engineering Center
P.O. Box 3368 University Station
Charlottesville, VA 22903

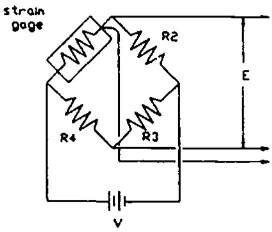


**Figure 2:** Wheatstone Bridge Circuit

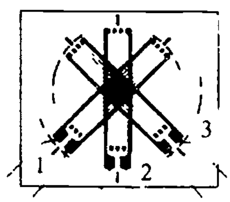


**Figure 1:** Rectangular Strain Gage Rosette

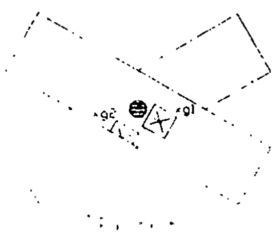

**Figure 3:** Location of Strain Gages on Cross Tubes

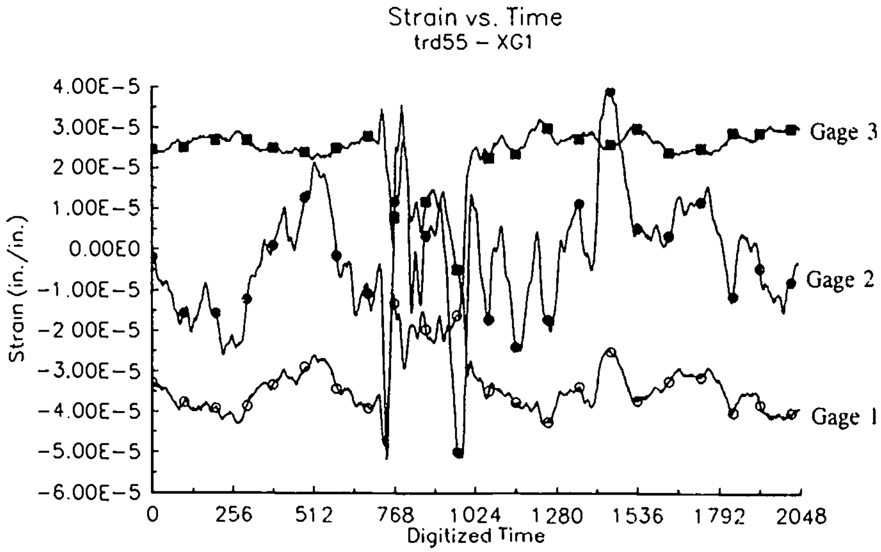


**Figure 4:** Strain vs. Time History for a Treadmill Test

# Using ISO Standards for Manual Wheelchair Testing: The Hong Kong Experience

Eric W.C. Tam, Eddie Y.M. Chiu, John H. Evans
Rehabilitation Engineering Centre
Hong Kong Polytechnic
Hong Kong

Abstract

The formulation of test standards for wheelchairs through the ISO is at its final stage. Our centre is among the first ones in Asia to use these standards in performing wheelchair testing. This paper discuss the Centre's experience in conducting such tests, including the difficulties encountered and the possible interpretation of the results from the end user's perspectives.

## Introduction

Wheelchair selection is not a easy task without a detailed knowledge of what is available on the market. Without seeing the actual product, one would be highly dependent upon the information disclosed by the manufacturers catalogues or specification sheets. Such information is limited to dimensional specifications and confusions often arise due to the use of non-standard measuring and reporting techniques.

In view of these facts, an international standard has been developed which specifies standard testing and measurement procedures to disclose wheelchair performance and comparable dimensional information. Although, wheelchair manufacturers in Hong Kong and nearby countries are expected to adopt this new standard in the future, this would proporly follow any similar actions taken by traditional industrialised countries. This will disadvantage the local consumers because product comparisons will be difficult.

In order to facilitate the process of information disclosure, a collaborative project is conducted by our centre and the local Consumer Council, aiming to define and disclose relevant comparable data on a representative sample of manual wheelchairs available in Hong Kong.

## Method

Adopting from the International Standards Organization (ISO) part 7176 on wheelchair testing, all tests relevant to the evaluation of manual wheelchair were included in the test protocol. These included:

| | |
|---|---|
| ISO 7176/1 - | Static stability [Published] |
| ISO 7176/3 - | Efficiency of brakes (evaluation of parking brakes only) [Published] |
| ISO 7176/5 - | Dimension, mass and turning space [Published] |
| ISO 7176/7 - | Determination of seating dimensions [Prior to approval] |
| ISO 7176/8 - | Static, impact and fatigue strength tests [Prior to approval] |

Wheelchair test samples were selected according to their representiveness in the local market. The six types of wheelchairs selected for testing are manufactured either in China, Taiwan, Japan or USA. These chairs were widely used in government hospitals, rehabilitation centres and by individuals. The price range of these chairs is from HK$ 900 to 4,000 (US$ 120 to 500). Due to financial constraints, only 3 samples of each wheelchair model were tested. Further, to ensure the representiveness of these samples, the purchase of these chairs was arranged through a medical rehabilitation centre, so that the suppliers were not aware of our intention to test.

## Discussion

### Equipment construction

ISO specified tests on wheelchair evaluation involved in the use of various dedicated apparatus. These include:the test dummy, the reference loader gauge, the ISO 2-drum tester, the inclination test plane and other apparatus for static/impact strength tests. Equipment construction information were well documented for the published parts of the standard, whereas for those parts that are still prior to final approval, the following difficulties were experienced during the construction of test apparatus.

In part 7 of the standard, the width of the two slots (as viewed from the top view) located in the fore position of the Reference Loader Gauge was not indicated. Besides, the position for putting construction weights on the seat unit was not mentioned, but it can be estimated from the pre-defined position of the centre of gravity of the Loader Gauge unit.

In part 8, although it appears that there was a lot of information for equipment constructions, the following queries were encountered: (a) In static strength tests, a force applicator was required for loading different wheelchair components at different locations. However, there is limited information on the design of such apparatus, especially on how to set up the equipment for various loading application. (b) In impact strength test, construction of the standard load mass requires the filling of lead shots to a size 5 soccer ball. Instead of filling lead shots through the valve, our experience found that it may be more efficient to open up the ball to put the lead shots (or steel balls) in; since the ball would be completely filled when the desired mass was met. Further, we found that even size 5 soccer ball has some variations in actual dimension depending on the manufacturer. (c) Again, limited information is provided for the description of the 'ISO 2-drum tester'. This equipment is a substantial one. Therefore, if possible, technical details should be included. Our tester is primarily based on the University of Virginia model [1].

### Test procedures

Although the wheelchair standard was divided into different parts with specific test objectives, they should be always viewed as a complete set to avoid redundant test procedures.

In part 3, parking brake test, the evaluation procedure was basically the same as indicated in the first part of the static stability test. Some remark should be included in the standard so as to avoid test redundance. In part 7, the criteria for using the test dummy to replace the reference loader gauge (RLG) is not clearly defined. This would introduce incomparability between results. Our suggestion is that the RLG should be the only test mass for this part of the test. Furthermore, there was no specification on how the RLG weight distribution should alter with respect to the testing of children size wheelchair. In part 8, these tests are destructive, and all strength tests has to be performed before the fatigue test. This may cause damage not readily observable with naked eyes to the chair which would not be documented. Further, in order to best represent the anthropometric data of local adult, we used a test dummy which weights 63 kg; with proportional component mass as set in part 11.

Data interpretation

The ability to do a wheelie is essential in maneuvering a wheelchair for daily activities, such as curb climbing. The ease with which the wheelchair can be controlled (balanced) is related to the static stability of the chair. ISO 7176/1 reviewed the tipping angle (centre-of-gravity angle) of the wheelchair, which provide the user an idea of how easy a wheelie can be performed [2,3].

Wheelchair access guideline usually recommended a 1:12 slope ramp surface for safety operation of manual wheelchair. However, in daily activities, steeper slope will often be encountered. Therefore, understanding of the wheelchair's static stability and its parking brake reliability can minimize any hazardous slope climb.

Dimensional information is essential in the selection of a suitable chair. ISO 7176/5 reported these information according to the definitions as specified in ISO 6440. The dimensional data reported were under an unloaded situation. Because of the sling seat and flexible backrest design in traditional wheelchairs, some dimensional data will alter under a loaded situation. Part 7 of the standard was incorporated for such purpose. A full understanding of these information will enhance the accuracy in selecting a suitable chair.

One primary concern from the user's perspective is the durability of the wheelchair. Although part 8 of the standards is designed to evaluate such parameters, when reporting test results, it must be presented within the comprehension of an user. For example, the result of the double drum fatigue test should report the number of years of life expectance of the chair rather than the number of cycles to fatigue.

The efficiency and effectiveness of the propulsion of wheelchair is another concern by the wheelchair users. The tests within the standard has already extracted ergonomic parameters, however, the prescriber/consumer has to interpret these information to achieve optimal performance based on his understanding. Examples include: (a) the weight (part 5) of the chair and the toe in/out angle (part 8) reviews the rolling resistance of the chair, (b) the flexibility of the seat height adjustment (part 5 & 7) will influence the economy of propulsion, (c) the weight distribution together with the seat position (part 5) affects the downhill turning tendency, the Yaw Axis Control ... etc. and ultimately the propulsion efficiency [4,5].

Conclusion

Upon the finalization of all the ISO standards for wheelchair testing, wheelchair users will be able to compare both dimensional, durability, and performance information as disclosed by manufacturers according to the standard. As discussed earlier, a meaningful interpretation of these test results would be an important aspect to consider from the user's perspective, because this will lead to an effective and efficient performance. The knowledge obtained from our work in testing wheelchairs will not only beneficial to the consumer, but can also aware local rehabilitation professionals about this advancement in the subject.

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Address

Eric W C Tam
Rehabilitation Engineering Centre
Hong Kong Polytechnic
Hunghom, Kowloon
Hong Kong

# An Improved Design of a 100 Kilogram ISO/RESNA Wheelchair Test Dummy

Rory Cooper, James Ster III, Craig Myren, David Pettit
Human Engineering Laboratory and Rehabilitation Engineering Program
Department of Biomedical Engineering
California State University, Sacramento

**ABSTRACT**

Wheelchair standards have been in development for several years. A set of tests has been approved by the American National Standards Institute (ANSI) and by the International Standards Organization (ISO). Normative values remain to be developed for the approved wheelchair tests, and the tests themselves need to be refined. Test dummies are intended for tests in which the wheelchair is required to be loaded. With the large variety of wheelchairs to be tested there is need for some modifications to the dummies. The choice of materials and design can make a wheelchair test dummy more useful.

## Background

There are numerous persons in the United States who rely on wheelchairs for their mobility, and for their well being. Wheelchairs are required for recreation, vocation and nearly every other regular activity for persons with mobility impairments. Nearly 1.2 million Americans use wheelchairs as their primary source of mobility (Pope A.M., Tarlov A.R., 1991.). This translates into a substantial number of people depending on research in wheeled mobility for their quality of life.

Standards are required to establish minimum performance and durability criteria for wheelchairs. Standards benefit consumers, manufacturers and third party providers. The ANSI Technical Advisory Group (TAG), organized by RESNA is made up of representatives from many different disciplines (McLaurin, C.A., Axelson P., 1990.). This helps to ensure that engineering, ergonomic, aesthetic and performance needs are considered. Standards help manufacturers in comparing their products on a quantitative basis with other manufacturers' products, and with establishing minimum design criteria. Consumers benefit by being able to evaluate wheelchairs before they are purchased. Purchasing agencies are assisted in establishing reasonable acceptance criteria.

The development of standards is the first major step in a long process. Standards consist of two primary components: 1) Tests and 2) Normative Values. The tests have been developed, though no doubt there will be some refinement. The normative values can only come by applying the tests. This process is presently underway. The development of normative values is most likely to show several things, not the least of which are: 1) the need to modify some of the standards, 2) the need for independent evaluation, 3) the need for disclosure.

This paper shall focus on some improvements in the design of wheelchair test dummies (ISO 7176/11 or RESNA WC/11). There are four dummies used for wheelchair testing (25, 50, 75, 100 kg.). Dummies can be used for all tests where the wheelchair is to be loaded. The ISO standard is based upon simple and inexpensive construction with mass distribution similar to a human.

## Statement of the Problem

The dummies described in the ISO/RESNA standards are fragile, very difficult to handle and do not work with most ultra-light wheelchairs. The objective of this design project was to develop a test dummy which meets ISO/RESNA standards (at least intentions) but is more durable, safer to handle and could be used with ultra-light wheelchairs with narrow footrests as well as classical designs.

## Rationale

The ISO/RESNA dummy should be similar in anthropometry to a human wheelchair rider and should be much more durable than any wheelchair being tested. The dummy should not fail , especially during dynamic testing, before the wheelchair. The plywood suggested for the body in the standard is too weak to withstand more than a few fatigue tests. The feet of the dummy should be able to rest properly on the footrest(s) of a wide variety of wheelchairs, including those with tapered front ends. The design suggested in the standard has legs which are too short to reach most footrests and the feet are too wide to sit on tapered footrests. The dummy should be safer to handle. The 100 kg. dummy is very awkward to lift and place in a wheelchair, especially on an ISO/RESNA Double Drum Tester.

## Design

The design outlined here was for a 100 kg. test dummy. However, the process could be extended to the other sizes as well.

Design Criteria:

1) The dummy was to meet the intent of ISO/RESNA standards.

2) The dummy was to be capable of withstanding 10 million cycles in a wheelchair on an ISO/RESNA Double Drum Tester (this is approximately equivalent to 100 tests).

3) The leg length and foot width were to be adjustable to accommodate a wider variety of wheelchair designs.

4) The dummy was to be safer to use.

### Material Selection

The dummy frame was constructed of half inch aluminum (6061T6) plate. This material was selected because it is a relatively inexpensive structural aluminum, which is easy to machine, and is widely available. The ISO/RESNA standards call for dummies to be simple to construct and inexpensive. Although the initial investment for aluminum is higher than for plywood, the long term cost should be lower because of extended product life Aluminum is light weight, as is plywood, and therefor adequate freedom remains to adjust mass distribution. Steel plates were used for additional mass. Steel is very durable, is readily available and is easy to work with. All fasteners were grade 8.

### Frame Geometry

The back and seat were constructed as per ISO/RESNA standards (Figure 1). The seat was modified by running a one inch steel bar across the knee joints of the dummy. The steel bar acts as a pivot (knee) for the lower legs and permits the lower leg width to be adjusted (Figure 1). The dummy has two lower legs connected to a common knee shaft (set screws are used to maintain the desired width). This allows the width between the lower legs to be adjusted (range is 200 to 250 mm) to accommodate a variety of footrest widths. The length of the lower legs is also adjustable by bolting a dovetailed bar onto the shaft attached between the knees (range is 300 to 500 mm). Two half inch diameter Allen cap screws hold the plates together.

The dummy was equipped with eyelets at the shoulders, so that straps could easily be mounted to the dummy to lift it with a motor hoist.

## Development

The design specifications developed out of experience gained by testing wheelchairs using a standard ISO 100 kg. dummy (or 250 pound dummy). Upon testing a variety of styles of wheelchairs from several manufacturers, it was discovered that nearly each chair required some modification to the dummy in order for the chair to be properly tested. In addition, placing the dummy in the wheelchair was particularly difficult, and sometimes potentially hazardous. This task often required several people working together. Hence, some means of using a hoist was investigated.

Typically, wheelchairs are tested for approximately 100,000 cycles on an ISO/RESNA Double Drum Tester, and 3500 cycles on an ISO/RESNA Curb Drop Tester. These tests can be particularly punishing to the dummy. It was considered undesirable to have to replace the dummy regularly, therefor the decision was made to construct the dummy frame of aluminum rather than plywood.

The dummy was constructed first by laying the parts out on pieces of aluminum. The parts were than rough cut on a band saw, and finished cut on a milling machine. The final finish work was done by hand. Holes were drilled and tapped to bolt the dummy's frame together. The components (back, seat, legs) of the dummy's frame were weighed than appropriate steel weights were cut and bolted to the frame in the proper locations. The frame was bolted together. An adhesive was applied to all bolts to inhibit loosening. High density foam was glued to the back, seat and feet to protect wheelchairs from the dummy's frame.

## Evaluation

The new dummy has survived over 200,000 cycles on an ISO/RESNA Double Drum Tester without any signs of wear or fatigue. The leg width and knee adjustments have held their place during each testing trial. The dummy has experienced no loosening of any of the bolts or screws which hold it together. There has been some breakdown in the foam and some damage to the foam due to handling.

The dummy has not required further modification to test some of the newer wheelchair designs. However, the dummy may require modification for future wheelchair designs if they vary dramatically from present forms.

The integration of eye hooks and the use of a motor hoist has made handling the dummy noticeably easier.

## Discussion

Several improvements to ISO/RESNA dummies can still be made. The standards do not specify how the mass is to be distributed within each component (i.e. the torso). This may cause undue stresses in some areas of the wheelchair. If the dummies are to be used for vibration analysis (e.g. ride comfort) than dummies which model human vibrational properties need to be developed. It has been suggested that a patient transfer hoist works well when transporting test dummies. The ISO Standard 7176/11 and RESNA WC/11 should be changed to suggest aluminum instead of plywood, and the leg length and width should be made adjustable.

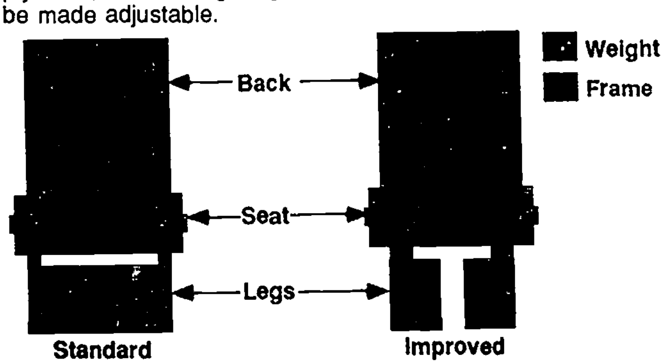


**Figure 1. Front View of Standard and Improved ISO/RESNA Wheelchair Test Dummies**

## Acknowledgements

This project was partially supported by Rehabilitation Services Administration, U.S. Department of Education under Award No. H129E00005, Quickie Designs Inc., and the Human Engineering Laboratory of California State University, Sacramento.

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Rory A. Cooper
Coordinator
Rehabilitation Engineering Program
Biomedical Engineering Department
California State University
Sacramento, California 95819-6019

# Easter Seal Student Design Competition

# 1992 Easter Seal Student Design Competition

On the following pages you have the opportunity to read six exceptional student design papers. This year, 34 creative projects were submitted to compete in the annual Easter Seal Student Design Competition. Choosing only five winners and a runner-up was, to say the least, a challenge for the eight-member review panel. Yet, the papers you are about to read were chosen as outstanding examples of functional and practical design solutions on the basis of:

- technical competence of the design
- relevancy to real societal needs
- creativity and innovation
- manufacturability and marketing potential
- safety and durability
- clinical testing and durability
- cost effectiveness
- aesthetics of final prototype
- consumer appeal

The National Easter Seal Society (NESS) continues to make this most worthwhile event possible by providing the winners with round-trip air transportation to the RESNA Conference, complimentary room, conference registration, and a stipend for meals. Exhibit space is provided at the conference, offering a great opportunity for the winning students to share their projects and rub elbows with others involved in the development and direct applications of assistive technology.

These students and their projects represent an energy source that is exciting to see and needed by our profession. They fit well into our conference theme **"Technology for Consumers."**

Ironically, one of our winners, having just come through the trauma of loosing a family member, relayed how he had seriously considered <u>not</u> bothering to enter. We are all so glad that he did, for his project addressed a very real and present need, and it proves so true the quote from Publisher's Clearinghouse, **"You can't win if you don't send it in."**

In my opinion, everyone who enters our competition is a winner! They are all experimenting with investing their knowledge, skills, and abilities in bettering the quality of life for people who have been challenged by disabilities. We applaud them all. In no way do we imply insignificance to those projects not chosen. Our judging panel however, unanimously concluded that these six papers represented projects that scientifically, yet pragmatically intervened to solve "real world" needs, which makes them of greater overall appeal and benefit to consumers and commercial producers alike.

After all, linking appropriate technology to the largest possible group of beneficiaries, is what successful R&D is about. These projects excel in that potential, and I am very proud to present them to you.

RESNA wishes to thank NESS for its continued support of the Student Design Competition, the judging panel for a job well done, and all of the students who took the time and effort to submit quality projects.

Please welcome the five finalists to RESNA International '92, and be sure to encourage these budding Rehab Engineers to stick with us as RESNA and NESS continue to identify and reward such **"Towering Achievements."**

David F. Law, Jr.
Chairman
Easter Seal Student Design Competition

# DESIGN OF TRANSPORTABLE BATHING SUPPORT DEVICE FOR PEOPLE WITH CEREBRAL PALSY

John Melvin, John Bernhardt
Bill Hanser
Department of Mechanical Engineering
Montana State University

**Abstract**

A bathing support device was required for our client and people in general with athetoid cerebral palsy. A specific, geometry was needed for the bathing support device was needed to reduce and constrain the strong, involuntary muscle contractions of our client. Our design also reduces the degree of lifting involved in transferring the bather in and out of the device by eliminating extended lifting over the edge of the bathtub. Also, since our client can not walk, we felt it would be convenient if the device itself were mobile, thus providing transport to and from the bathing area, and eliminating the inconvenience of an additional transport device.

**Background**

As we researched existing bathing support devices and spoke with numerous specialists in the field, including physical therapists, seating specialists, a physiatrist, the child's mother, and several of the major companies currently manufacturing bathing supports, we found that there is currently nothing commercially available that meets the specific needs of a person with athetoid cerebral palsy. This need is specifically to restrain the person to a certain geometry which greatly reduces their spastic muscle reflexes. As a result we set forth to design a product that not only met our clients needs, but also would meet the universal need for a bathing support for people with athetoid cerebral palsy.

The effectiveness and marketability of our design is reinforced by our work with a major rehabilitation device manufacturer who is researching production of our device for the public.

**Design Objectives and Criteria**

Our objective was to design and construct a bathing support device that not only met the needs of our client, but would be effective for any person with a similar disability, and universally capable of adapting to their bathing facility.

**Design Criteria**

1. Most importantly the design had to comfortably restrain the bather in the necessary body geometry needed to control their muscle contractions. Specifically this meant reducing the angle between the knees and abdomen, the hip angle, to less than 90 degrees.

2. The device had to reduce the work and amount of lifting required by the bathing attendant.

3. The device had to be universally adaptable to each client's bathing situation, as well as be removable, when not in use, in order to allow others use of the bathing facility.

4. The device had to have a low cost in order to make it available to the average person in need of such a device.

**Description of the Device**

There are three distinct parts to our final design: the bathing support itself; a mobile cart, used to transfer the support device; and a removable, folding rail structure mounted in the bathtub. During bathing, the one piece rail system is removed from a storage area and mounted in t e bathtub via two locking clamp attaching to the bathtub walls, and four suction cups attaching to the tub floor. The attendant then loads the bather on the support device from a convenient location in the house. The support is transported into the bathroom using the mobile cart. The mobile cart and the bath rail system are locked together for safety, and the support device is slid from the cart onto the rail support in the bathtub. After bathing the procedure is reversed.

The frame of the bathing support was made of 1.5 inch, schedule 80 PVC pipe. We chose PVC for several reasons: it has a reasonably high structural strength and is lightweight, easy to work with, and it is not affected by the moisture and detergent of the bathtub environment. The support material text, a vinyl coated nylon mesh, that is extremely high in strength, non-abrasive to the skin, and not affected by the bathtub environment. We also felt there was a need for support belts and pads. The neck pad holds the head in place, preventing injury, while also providing a comfortable position. The hip and ankle belts provide the constraint necessary to prevent the bather from falling from the support, and to minimize uncontrolled muscle reflexes.

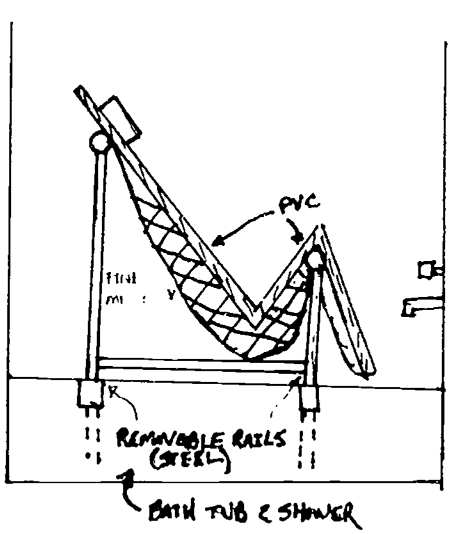
The transfer cart is constructed from one inch diameter, 0.083 inch wall thickness, stainless steel pipe. Stainless steel is used for strength purposes so that it will withstand the dynamic use around the house, and resist corrosion from the water. A set of four, one inch wide and six inches in diameter, castors provides easy maneuverability on all household flooring surfaces.

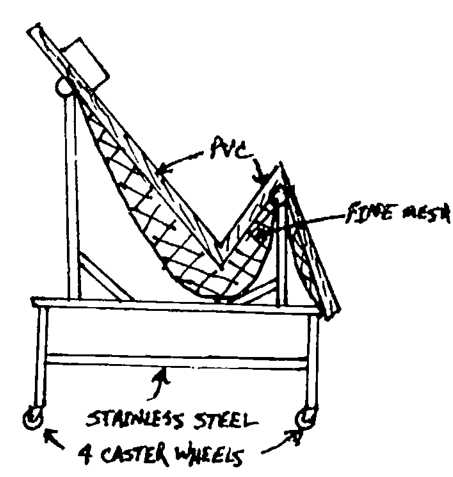
The bathtub rail system is constructed of water sealant coated, lightweight metal. It is a one piece design, hinged in three places with two sets of locks to rigidly hold the device while in use. The rail system easily collapses into a five inch wide unit requiring a minimum of storage space. The male end of the rail system, on both the transfer cart and in the bathtub, is stainless steel, while the female end connected to the bath chair itself is PVC. This allows the device to be easily slid over the stainless steel surface during transfer.

Finally, the design is adaptable to a roll in shower. The cart is designed to withstand the moisture of the shower, and the rail system is simply no longer used.

**Safety**

During the design and construction of this project the safety of the bather and the attendant was of premiere importance. Considerations included the



stability of the cart. The transport cart, with the loaded support device attached, had to meet the rigorous (wheelchair specifications?) for stability. Also, the entire system was subjected to a rigorous testing procedure including static, dynamic and impact testing. The system also contains a number of locking and restraint mechanisms to prevent injury. The entire design and its operation was made as straightforward as possible, for the purpose of eliminating user error, or misuse.

**Conclusions**

There is a definite need for a bathing support device of this nature for people with athetoid cerebral palsy, and other similar disabilities. We feel our design meets this need. We are also hopeful that the universal design we have pursued for reasons of marketability will lead to the commercial production of this device, and its availability to anyone with a similar need.

**Acknowledgements**

Financial support was provided by the National Science Foundation and the Mechanical Engineering Department of Montana State University. We would also like to thank Michael Kaan of Columbia Medical Manufacturing of Pacific Palisades, CA for his companies donation of a head rest as well as valuable insights and information.

Bill Hanser
101 J Paisley Ct
Bozeman, MT 59715

8.8

# Mounting System for Communication Devices on Wheelchairs

Sylvie Verwaayen
Fanshawe College, Industrial Design- Class of 1991
London, Ontario, Canada

## Introduction

A system for mounting communication devices on wheelchairs has been designed. It allows the communication device to be brought from a storage position behind the chair to an operating position in front of the user and vice versa.

## Statement of Problem

Many AAC device users in wheelchairs and their facilitators experience difficulties with moving a current device into the right position for operation and moving it out of the way when the space in front of the user is needed for other puposes. At present, there are no fully flexible mounting systems for AAC devices on different models of wheelchairs.

## Background

Many users of augmentative and alternative communication (AAC) devices use wheelchairs permanently. Thames Valley Children's Centre is one of the level-three centres in the province of Ontario for the provision of advanced AAC devices. At the centre, severely disabled children are prescribed and fitted with wheelchairs as well as communication devices and other assistive technology. The devices are mounted on the wheelchairs in the centre's Seating and Mobility Service. The AAC device must be mounted on the chair in such a way that it can be easily accessed and operated.

## Rationale

In order to use the communication device optimally, the user should be able to bring it forward to an operating position in front when needed and move it to a storage position when preparing for other activities.

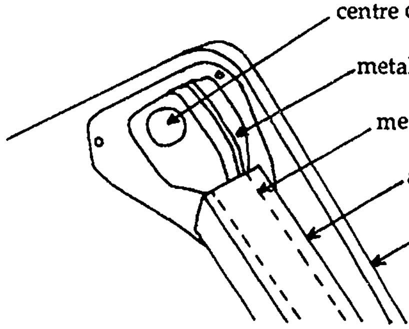
The most suitable storage position was determined to be behind the backrest of the seat.

In the first stage of this project, a system was designed that would allow a facilitator to easily move the communication device. In a second stage the system will be motorized to provide easy operation by the device user.

## Research

In the Industrial Design course at Fanshawe College, students are encouraged to seek answers to design problems in unconventional and otherwise unrelated areas.

The first piece of the design puzzle came from an amphitheatre tablet. The rotating and pivoting properties of this object was just what was needed. *See diagram below*.



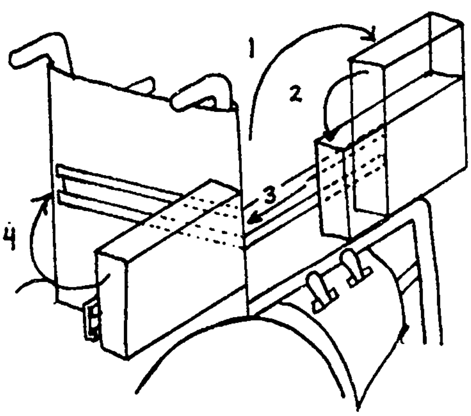

Second, drawer tracks that worked on a ball bearing concept were purchased. This was the largest stumbling block because the tracks had stoppers at one end and this was in the way of the workboard transferring from one track to another.

## Design

The design work started with detailed measurements of wheelchairs as well as the workboard on which the AAC device is mounted. Consideration had to be given to other pieces of equipment attached to the wheelchair such as head switches, joystick, foot rests and battery.

Four different concepts for moving the workboard between the two positions were studied. The one selected was a sliding motion along the side of the chair with a pivoting point where the armrest meets the back rest.

The communication device sits on a workboard which can be pivoted *and* rotated. When moving the device away from the operating position, the workboard is brought to the side of the wheelchair outside the armrest. It then slides back to the point where the armrest meets the backrest. Meanwhile, the second part of the sliding mechanism is transferred to the back track and secured in a position along the back of the chair. *See fig. below*




1 Rotate to the side of the chair
2 Pivot down
3 Transfer to the back track
4 Swing behind seat

### Development

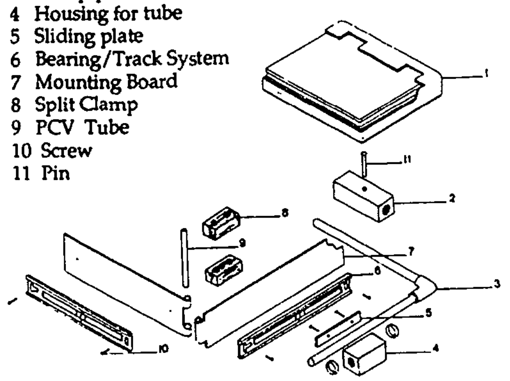
An initial model was made from blue foam, PVC pipe and a drawer slide mechanism with a bearing track system. From that model, the pivot and rotating mechanism were elaborated and eventually incorporated into one mechanism*(drafting available).*

Next, a prototype was made out of wood, PVC pipe and a drawer mechanism . Special care was taken to ensure that the two tracks would mate and the plate with the workboard would smoothly transfer from one track to the other.

The prototype was evaluated by staff at the Thames Valley Children's Centre. Based on their suggestion, a third prototype was made out of steel.This version was also equipped with clamps for attachment to a wheelchair. The prototype was mounted on a standard wheelchair and displayed at the MEDTECH show in London, Ontario, Canada.

Exploded view of final concept design:

1 Laptop and case
2 Pivot/Rotate Mechanism
3 PVC pipe
4 Housing for tube
5 Sliding plate
6 Bearing/Track System
7 Mounting Board
8 Split Clamp
9 PCV Tube
10 Screw
11 Pin



### Future Developments

In the spring of 1992, this design will be carried on by engineering student(s) from Sweden that are on a work-term at Thames Valley Children's Centre.

### Aknowledgments

A most sincere Thank You to the professionals at Thames Valley Children's Centre. For their support and encouragement throughout the entire project, as well as on future development of this design.

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### Address

Sylvie Verwaayen
792 Monsarrat Avenue
London, Ontario, Canada
N5Y 4Y5

9.9

# LARGE-BUTTON REMOTE CONTROL FOR PERSONS WITH MOTOR FUNCTION DISABILITES

John I. Ramalho
Manufacturing Engineering Technology
Western Washington University
Bellingham, Washington USA

Abstract

A large-button version of the everyday remote control used for television, video cassette recorder (VCR) and compact disc player (CD) entertainment systems is an ideal instrument for the person with motor control disabilities. The designs of commercial models do not lend themselves to the needs of this group of people; the keys are too small, too close together, and require too much force to press. Adapting a commercially available reprogrammable remote control by incorporating larger buttons which require less force to activate, would produce a device that could be operated by those with motor function disabilities. This paper outlines the design, production, and usefulness of a large-button remote control.

**Introduction: A Brief History**

The usefulness of the familiar remote controls used to operate various popular entertainment systems such as TVs, VCRs, and stereo/CD players is often taken for granted. However, many persons disabled by lack of motor function of one sort or another, would find great benefit and independence through the use of such a device. Unfortunately, commercial remote controls are not designed with the disabled person in mind; the buttons are small, placed close together, and require too great an effort to press. Such an arrangement makes it almost impossible for those with impaired motor function to operate. As a result it is necessary for the disabled person to rely on an assistant to perform this otherwise mundane task. A remote control designed with the disabled in mind would return to the individual a simple, but significant independence, and at the same time provide the assistant additional time to perform more vital tasks.

A large-button remote control could be used by individuals with a wide variety of disabilities. Persons targeted for such a product would include: para- and quadraplegics, persons with multiple sclerosis, arthritis, cerebral palsy, carpal tunnel syndrome, absence of major appendages, limited eyesight or blindness or any person who has had an accident that produced a temporary debilitation. Even the average person who finds searching for the small buttons tedious would benefit.

According to the National Institute on Disability and Rehabilitation Research 1983-1985 (Table 1), the number of United States civilian noninstitutionalized persons with the permanent disabilities mentioned above was reported to be about 20% of the population (LaPlante 1988). Although many of these disabilities are minor in nature, these persons could still benefit from such a large-button device.

The large-button remote control described here makes use of a commercial reprogrammable remote control. Fourteen large, 1" x 1", keys press small switches mounted in a case housing the commercial remote. These keys provide complete operation of power, volume, channel, mute, rewind, fastforward, play, record, stop, pause and item select functions. Flexible circuitry connects the switches to the commercial circuit board. The large-button remote case measures 7.5" long, 3" wide and 1.75" high and weighs less than 7 oz. The back of the case opens to provide access to the commercial remote for battery changing and programming.

**Methodology**

Initially, a local physician associated with the local chapter of the Volunteer's for Medical Engineering (VME) came to our university requesting help in designing a remote control for TV to help a multiple sclerosis patient. With funding assistance from the St. Luke's Foundation, a prototype device was developed.

**Initial Design:**
The initial design parameters called for an aesthetically pleasing device with large keys capable of being activated with a slight amount of pressure. The device had to make use of existing accessible technology, yet must remain cost effective enough to allow those who could benefit to purchase the unit. Initially, manufacturability was not considered significant since only of few were to be made. The switches were located first since these would determine the configuration and size of the large-button remote. Switches with an operating force of 130 ± 10 grams (gf) that could mount easily on a PC board were chosen for the design.

The first prototype was constructed of oak and acrylic and was easily produced. The case had six, 1" x keys for TV operation, measured 4" x 7" x 2", and weighed 1.4 lbs. The time consuming process in manufacturing was soldering the wire circuitry to the switches to the commercial remote's circuit board.

Incorporating VCR and Stereo/CD player control was considered a positive addition and a second prototype was produced. The addition of eight keys for a total of fourteen was required to handle additional operating modes. Oak was no longer a viable material since its strength to mass ratio would produce a prototype twice the size and weight. The possibility of producing more than just 2 remotes was added to the equation, making the manufacturing time required for each unit a concern. It was decided that computer numerical controlled (CNC) machining would be used to produce the cases. Aluminum was the material of choice. It was light, strong, easily machined, and would reduce the size while still allowing for the increased number of keys.

The second prototype produced contained fourteen keys, measured 7.5" x 3" x 2" and weighed 1.5 lbs (only 1.6 oz more than the oak model). Unfortunately, because of the amount of metal removal required, the machining time took 13 hours for each unit. The other manufacturing problem was the 2 hours required to strip and solder the wires to the contacts of the switches to the commercial remote's circuit board.

**Table 1: Prevalence of selected impairments and chronic conditions, United States civilian noninstitutionalized population, 1983-1985 (Three-year average).**

| Chronic Condition | All Persons # of conditions (in 1000s) |
|---|---|
| Skin and musculoskeletal | |
| Rheumatoid arthritis | 1,287 |
| Osteoarthritis/arthropathies | 29,033 |
| Bursitis | 4,684 |
| Impairments | |
| Absence of major apendages | 365 |
| Complete paralysis of extremeties | 650 |
| Cerebral Palsy | 262 |
| Partial paralysis of extre. | 541 |
| impairment of upper extre. | 3,109 |
| Blind both eyes | 381 |
| Cataracts | 5,221 |
| Glaucoma | 1,709 |
| other visual impairment | 8,554 |
| Miscellaneous | |
| Epilepsy | 1,043 |
| Multiple Sclerosis | 151 |

Both prototypes were taken to the local VME meeting to be examined and tested by persons with motor control disabilities. The response was enthusiastic. The keys where easily operated by a quadriplegic with only 17% use of his right arm. The only contention was the product's weight. Though the keys were easily pressed, the actual weight of both prototypes made it difficult to manipulate.

The engineers and health care professionals present at the VME meeting thought that the possible demand for such a product could be much greater than first anticipated and might justify injection mold production methods. Injection molding would ultimately reduce the 13 hour manufacturing time to a few minutes, increase ease of manufacturing, and drastically reduce product weight. Injection molding would also allow refining the design to increase the asthetically pleasing appearance of the product.

**The Final Design:**

The final design solution is presently in the process of production. It consists of a lightweight (7 oz), 5 part contoured case, adhesively bonded together, with the backplate and the keyboard removable for service (cleaning, battery replacement, and programming). All parts will be injection molded with acrylonitrile-butadiene-styrene (ABS). The window will be injection molded from ABS with methyl methacrylate additive used to give ABS transparent qualities. ABS was chosen for its impact resistance and toughness (from the butadiene), chemical resistance, heat stability, and aging resistance (from the acrylonitrile), and rigidity, high gloss and improved processing characteristics (from the polystyrene) (Whitlow 1988). In addition, ABS may be colored and is easily bonded with adhesives.

The circuitry required to connect the switches to the commercial circuit board had to be developed for easy manufacturing and installation. Wire stripping and soldering by hand was too time consuming, requiring as much as 2 hours per unit. Furthermore, the accuracy and dependability of the solder joints depended heavily on the skill of the technician. It was clear that an improved method was needed.

The idea of using of a conductive ink pen and a (Computer Aided Drafting) CAD drawing to plot the circuit with the ink pen in a pen-plotter was entertained. This method would require extensive pen mounting design and was discarded for a more reasonable silk-screening process. Silk-screening would provide for the rapid, accurate production of a flexible circuit on mylar. Two workers could produce as many as 100 circuits in less than 1 hour. The circuit design was created using AutoCAD and plotted on a Hewlett-Packard LaserJet III at 300 dpi resolution. A photographic image of the laser print was transferred onto transparent plastic. A high resolution silk-screen image was produced from the transparent plastic by a photo-curing process of the silk-screen polymer mask.

The practice of producing simple circuits using a silk-screening ink is an existing technology. Two basic processes were examined. One required the use of electrically conductive silk-screening ink most of which required curing by means of ultra violet (UV) light. This process, though simple, is cost prohibitive due to the silver conductive inks ("silvers") costing \$25 to \$45 per troy ounce. The silver ink method would cost a minimum of \$26.00/ circuit. The other process involved coating copper-clad polyester film with an etch-resist ink. After the ink dries the printed copper film is dipped in an etch tank filled with ferric-chloride. The ferric-chloride etchant removes all copper not coated with the etch-resist ink. After etching the ink is removed by solvent. Part 2 of this silk-screen process involves coating what is now the copper circuit pattern with a silk-screenable polyester solder mask. The silk-screen pattern for the polyester mask allows coating of the entire copper circuit except for the contact points which are to remain exposed for circuit connections. This method will require copper clad polyester film at \$1.00/square foot, etch resist ink at \$45/gallon, and polyester solder mask at \$45/gallon. This translates to a total cost of \$3.61/circuit and is the most cost effective of the two processes. Therefore, the etch-resist ink process was chosen as the best method to used.

The final hurdle involved bonding the flexible circuit to the switches and to the commercial remote control's circuit board. A one-part conductive epoxy used by the surface-mounted circuit board industry will be used. The epoxy requires a 12 hour cure time, and eventually may be applied by a robot using a glue dispensing end effector. Even when assembled by hand, the flexible circuit installation will take a maximum of 5 minutes per unit, a drastic reduction from the 2 hours required by the previous soldiering method. Furthermore, the skill requirements of the technician are almost completely eliminated.

**Aesthestics:**

The outward appearance of the large-button remote control is a smooth contoured design, with a finely textured "satin" black finish. The site-window required for the infrared signal to the TV, etc. will be a transparent smoke grey to match the case. All edges are rounded for increased holding comfort. More significantly, rounded corners remove any possibility of scratching from sharp edges. This is important especially when used by a person whose disability might inadvertently cause him to strike himself or another person.

The final design of the keyboard has been given a radius. This serves to remove the possibility of the keys being pressed in the event that the case is placed upside-down. The end

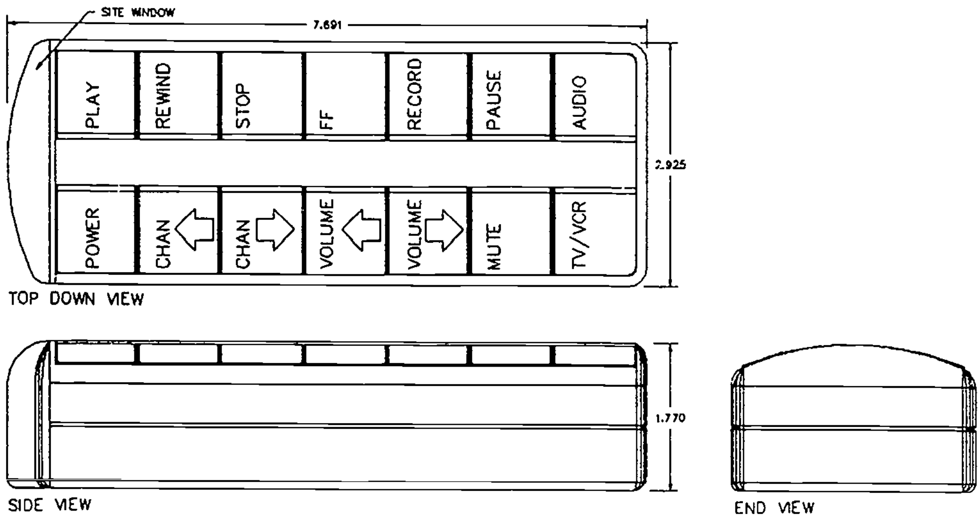


**Figure 1: Large-button remote control diagram showing top, side, and end views.**

result is that the batteries will not be discharged if the remote is accidentally left upside-down. Normally this is not a problem with a commercial remote's small keys which require greater force to activate. But this is an important concern when activation may take place under the large-button remote's own weight. With the curvature of the keyboard, the remote will orient so that none of the keys are activated.

**Development and Production**

The large-button remote control has been designed with robotic assembly in mind. The casing, switches, and circuitry can all be robotically assembled. However, it may take some time to produce all the fixturing necessary for total automated assembly. In the mean time, an entire remote can easily be hand assembled in 15 minutes, excluding the curing time required by the epoxy.

Actual production will be accomplished by student members of the Society of Manufacturing Engineers (SME) as a means of fund-raising and production experience. Funds gained by SME student chapter will be used for educational purposes. Chief among such purposes will be sending student members to professional meetings and conferences.

The product will be sold for a price that will cover the cost of the commercial remote (a major retail outlet has agreed to sell these at cost), the process materials and student labor. It is reasonable to expect the plastics materials to be provided via donations by various local industries. The product cost should be about $50/unit. Various organization like VME will most likely purchase the remote controls and see that they get to those needing the device.

The units will be distributed nationally through VME organizations located throughout the United States. It will be the responsibility of VME to order, ship and distribute the product.

**Conclusion**

Seldom does a product not originally design with the disabled community in mind, display the potential to meet the needs of the disabled as does the simple remote control of modern entertainment systems. Altered to address the special needs of those with motor function inpairments, the large-button remote control is a product which will give the disabled an increased independence. The concept of a large-button remote should by no means be limited to entertainment systems. Many household operations can be controlled from this same device when outfitted with existing radio frequency circuitry, i.e., window shade openers, light switches, intercoms, etc. The possibilities for such a device are limited only by the imagination.

**Acknowledgements**

Funding for research was provided by The St. Lukes Foundation.
Special thanks to Dr. John Ransom for introducing the idea of a large-button remote control, the many professors in the department for all their assistance, the students of plastics tooling class for their injection mold designs and machining work, and the Seattle chapter of the Society of Plastics Engineers (SPE) and the Volunteers for Medical Engineering (VME) for design recommendations.

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John I. Ramalho
Western Washington University
Manufacturing Engineering Technology
Bellingham, WA 98225

# DESIGN OF A DYNAMIC WHEELCHAIR BRAKE

Thomas A. Heil
Human Engineering Laboratory
California State University, Sacramento
Sacramento, CA

## ABSTRACT

Some quadriplegics having limited arm and hand function would prefer manual wheelchairs to electrically powered chairs but do not have the strength to operate them safely on steep or extended slopes. Existing wheel locks cause excessive tire wear. A dynamic wheelchair brake was designed to enhance the mobility and safety of this group.

A design was developed based on a simple band brake. The design calls for an aluminum disk mounted between the wheel and frame of the chair. This drum rides on a bearing concentric with the axle. A Kevlar jacketed cable wrapped around the drum provides friction for stopping. The drum engages the wheel by means of polyurethane wedges.

This brake is easy to use, reliable, and low maintenance. It is compatible with quick-release wheels, folding chairs, and wet weather. Materials for two brakes cost about $160. A prototype is being tested.

## INTRODUCTION

### Background

Quadriplegics with limited arm and hand function are known as marginal pushers. The development of wheelchair technology in the last decade has enabled this group to have the option of using a manual chair. Previously they had been restricted to electrically powered chairs. Manual chairs are lighter, smaller, easier to maneuver, and less expensive, so many marginal pushers prefer them.

Manual wheelchairs are normally propelled by a pushrim. Pushrims are light, reliable, and simple. They can be used for forward and reverse motion and as brakes. Most marginal pushers lack the strength or grip needed to use a pushrim effectively. This is compensated for by adding slip-resistant coatings or knobs to the pushrim.

### Justification

Unfortunately, these adaptions to aid motion eliminate the ability to use the pushrim as a brake. The need for an effective dynamic brake is widely recognized. Thacker, Seelye, and Kauzlarich of the University of Virginia reported the results of a 1985 survey of wheelchair users. Of 168 people surveyed, 81% expressed a desire for dynamic brakes [1].

Marginal pushers have lost control of their chairs on steep or extended slopes. The wheel locks now available on manual wheelchairs are effective parking brakes, but they cause excessive tire wear when used for dynamic braking. Designs for dynamic brakes have been proposed, but none have been widely adopted [2]. Wheelchair brakes will increase the mobility and safety of marginal pushers.

## APPROACH

### Research

The design team gained a solid background in wheelchair technology. They discovered what had been done before in the area of wheelchair brakes and reviewed braking technology. Books, as well as magazines, journals, and other periodicals were consulted. Wheeled mobility experts were consulted and marginal pushers interviewed. Materials specialists were contacted.

### Criteria

Once a thorough understanding of the problem had been obtained, the design team was able to identify eight features required in the design of an effective wheelchair brake:

1) *Reliability* -- Failure of the brake could lead to serious injury to the user, so the design must be very reliable. In addition, wheelchair users depend on their chairs. The chair must be ready to go twenty-four hours per day.

2) *Low Maintenance* -- A brake requiring frequent adjustments is inconvenient and will become unsafe.

3) *Compatibility with Quick-Release Wheels* -- The wheelchair's wheels often need to be removed to transport the chair. If the brake does not include this feature, it does not improve the user's mobility and independence.

4) *Compatibility with Folding Chairs* -- The braking system must not interfere with the folding mechanism.

5) *Good Performance in Wet Weather* -- Wheelchairs are used indoors and outdoors. Wet weather capability is essential for safety.

6) *Low Weight* - The marginal pusher is barely able to propel the chair, so any significant weight increase would be counterproductive.

7) *Durability* -- A high quality, durable product is necessary for dependability.

8) *Ease of Use* -- Since the marginal pusher has limited strength, the brake must be easy to operate. The two brakes, one on each s[illegible] of the chair, should operate independently to facilitate steering.

### Synthesis

The design developed is based on a simple band brake. An aluminum disk is mounted between the rear wheel and frame of the chair. It rides on a bearing and is concentric with the axle. A stainless steel cable in a braided Kevlar jacket is wrapped around the drum. Tension in the cable is controlled with a lever that is mounted to the frame. The Kevlar-aluminum interface provides friction for stopping. The aluminum drum engages the wheel by means of polyurethane wedges which fit snugly between the spokes of a standard plastic wheel.

This design, shown in Figures 1 and 2, satisfies all eight design criteria. Its simplicity and ruggedness provide for high reliability and durability. A sealed bearing is used, so no maintenance is required. The unique mounting system enables the brake to stay on the chair when the wheels are removed. Since the brake is mounted between the wheel and frame, it does not interfere with folding the chair.

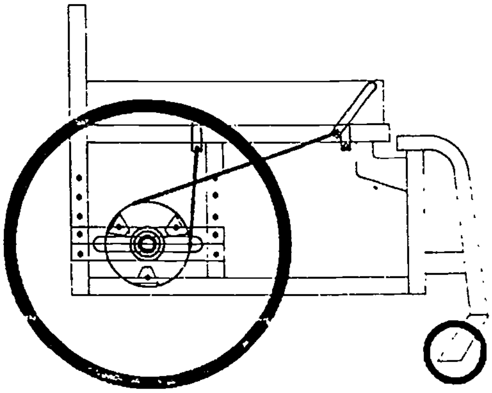

Figure 1. Wheelchair Dynamic Brake (side view)

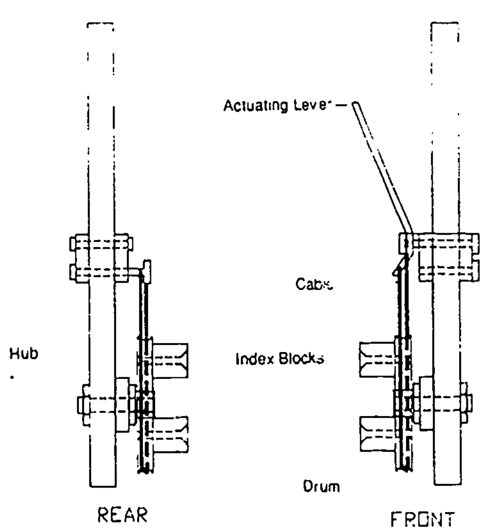


Figure 2. Wheelchair Dynamic Brake (end views)

The Kevlar-Aluminum interface has the distinctive property of an increased coefficient of friction when wet, so wet weather performance should exceed dry weather results. Another advantage of Kevlar is that its relatively low coefficient of friction limits maximum deceleration to about 0.2g. This is a safety feature because high deceleration could eject the rider from the chair. The use of aluminum in the design makes it light weight.

Calculations indicate that a three pound force on the actuating lever will provide maximum stopping power, locking the rear wheels. The progressive nature of a simple band brake creates this force multiplying feature and makes the device very easy to use.

## FABRICATION

Apparatus

The parts of the brake are: the hub, the drum, the wedges, the cable, and the actuating lever. Each has unique features discussed below.

A standard quick release wheel uses a ball-lock pin which slips through the center of a wheel and fits into a receiver. The receiver is threaded on the outside and two nuts secure it to a mounting plate. The hub, drum, receiver, and mounting plate are illustrated in Figure 3. The hub is a specialized nut that screws onto the receiver. It replaces one of the nuts holding the receiver to the mounting plate, enabling mounting of the brake without making the chair any wider.

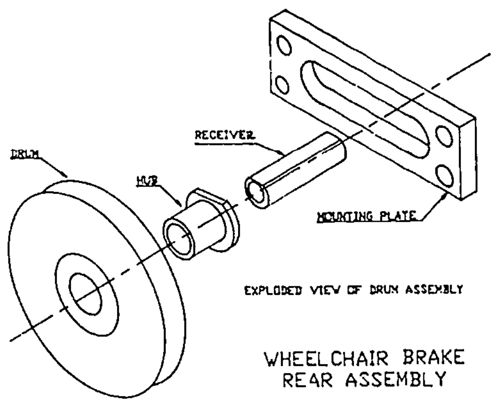


Figure 3

The drum is machined from aluminum. A bearing is pressed into a central hole and rides on the hub. A groove is machined in the outer edge of the drum for the cable to rest in. The drum is five inches in diameter. This size allows the drum to remain on the chair. It is small enough so that the portability of the chair is not impaired. Some of the team's earlier designs involved larger drums or channels attached to the wheel rim. These designs interfered with the user's hands and prevented quick-release operation.

Polyurethane wedges enable the drum to engage the wheel. The wedges fit snugly into the spaces between the spokes of a plastic wheel. They are bolted to the drum, which allows them to be removed and replaced with different wedges for different types of wheels. They are made of polyurethane so that they fit without slop and do not transmit excessive shear forces to the spokes.

A 1/16 inch diameter 7x7 stainless steel cable was selected. The use of stainless steel minimizes corrosion. The cable is covered with a woven Kevlar jacket. The idea of using Kevlar came from Royce Husted's Rim Band Brake [3]. Testing with bicycles indicates that the Kevlar tends to polish the aluminum instead of wearing it, providing superior durability.

The cable is stiff enough to spring slightly away from the drum when tension is reduced, so that the brake does not add significant drag. The high tension end of the cable is fitted with a swaged loop. A threaded swaged fitting on the low tension end provides adjustability. In normal use the brake would not need adjustment. This feature is provided in case the user needs to alter his or her wheel placement.

A standard Motion Designs Quickie type frame clamp was used to secure the tight side of the cable. A Motion Designs lever and clamp were selected to activate the brake. The lever has two places to attach the cable. One set-up will provide "push" activation; the other will provide "pull" activation. This is a valuable feature. Depending on their injury, some marginal pushers can only push and others can only pull.

Prototype

A prototype has been constructed. Preliminary testing has confirmed that the brake requires a low actuating force and does not create noticeable drag when the cable is slack.

Further testing is planned to explore the device's dynamic characteristics and determine if enough force is generated for the dynamic brake to double as a parking brake.

## CONCLUSIONS

While further study is required, and much testing remains to be done, this brake appears to fulfill the design criteria and work well.

## ACKNOWLEDGEMENTS

The design team consisted of:

Professor Leo Dabaghian, design supervisor
Professor Rory Cooper, design consultant
Thomas Heil, student design team leader
David Grant, student designer
Hugh Morrison, student designer
Frank Kozina, student designer

The design team wishes to thank James Ster and David Lightfoot for their assistance.

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Thomas A. Heil
Human Engineering Laboratory
California State University, Sacramento
6000 J Street
Sacramento, CA 95819

916-278-6647

# VEHICULAR TRAVEL RESTRAINT SYSTEM FOR DISABLED ADULTS

Perry B. Kirwan and William R. Norling
Department of Chemical, Bio and Materials Engineering
Arizona State University, Tempe, AZ 85287-6006, USA

## ABSTRACT

St. Michael's Association School for Special Education in Window Rock, AZ is home to over 150 disabled children and adults, many of whom have cerebral palsy. One of the problems associated with this condition is the lack of postural muscle control. The inability to sit erect in a vehicle can compromise the passenger's safety. Standard vehicular safety belt systems implicitly require the individual be able to sit upright. The students at St. Michael's can spend up to four hours riding over rough terrain to reach home or school. To date, no federal regulations apply to disabled adult travel restraint systems. A full size travel restraint system weighing under 17 lbs has been designed to meet this need. The system provides adjustable torso support and includes provisions for medically appropriate custom seating pads. A four point harness is attached to a padded LEXAN back support. Rigid torso support cushions are attached to the sides of the back rest and held in place with two inch wide nylon webbing. It is easily installed or removed in a vehicle by one person in under five minutes without the use of special tools.

## INTRODUCTION

### Problem statement

Many of the disabled students who attend St. Michael's school are wheelchair bound. The school is located in a remote section of Northeastern Arizona. Most are cerebral palsy children and adults without any significant degree of torso support. They range from 7 to 26 years of age and weigh from 70 to 120 lbs. The students must travel up to 150 miles over smooth and rough terrain in one of three school vehicles: a full sized school bus, a mini school bus and a four wheel drive Chevrolet Suburban. Currently, school vehicles provide no safety restraint system aside from the standard seat belts which work only if the passenger has sufficient trunk muscle motor control. In the school buses, seat belts are not required in the passenger compartment per federal law[1]. The disabled adults and older children are often too big for the largest size commercially available toddler seat, therefore, an alternative method of travel restraint is needed. A patent has been issued for a padded aluminum frame seat assembly that is attached to the vehicle frame by straps and a special hard point[2]. The difficulty with this device is that a special modification must be made to the vehicle to anchor the attachment straps pursuant to federal law[3]

### Design Objectives

The technical goal of this project is to create an inexpensive vehicular restraint system that provides the utmost in safety and medically appropriate physical support but does not overly constrain the individual. The materials for the system must be durable, lightweight and easy to maintain. The system must contain few working parts and be interchangeable between vehicles with minimal tools and effort. While satisfying the physical and mechanical requirements, the system must be responsive to the human needs. The restraint system should not be identifiable as a device for "the disabled."

## DESIGN METHODOLOGY

SAFETY is the primary design requirement. In the event of sudden decelerations such as a forward impact, the restraint system must (1) distribute the forces over the body to avoid injury and (2) not become a missile hazard that aggravates or produces additional trauma to the vehicle occupants.

The main portion of the travel restraint system consists of a specially designed piece of LEXAN (polycarbonate resin) that acts as the main weight bearing structure. The choice of 0.5 inch thick LEXAN for the base material was made as a result of the density (1.2 g/ml), high strength to weight ratio and durability (see Table 1). The stress analysis showed the assembly could easily withstand the required 30 mph (4000 lbf) federal crash test (see Table 2). A four point Nylon harness system is used to attach the passenger into the seat that parallels the design of most infant seats. The mechanical properties (strength and density) were such that a safety factor of three was obtained (Table 2). Two straps come over the rider's head and connect to a single buckle unit on the hip belt. This arrangement of straps is designed to distribute the retarding forces over body so not to cause/ aggravate injury in sudden decelerations. Side mounted torso support straps connect to the main harness assembly by loops around the upper straps. Details of all padding sub-assemblies are shown in Figure 1. The system cannot cause respiratory impairment in any posture or position. The design achieves this by using a method of restraint that avoids constriction of the diaphragm. The straps cross the shoulders and waist. The authors recommend that the torso straps be tightened to no more than the width of two fingers from the chest to reduce respiratory constriction.

Two 1" O.D. stainless steel U-hooks are mounted to the back plate with high strength 3/8" D bolts to keep the top of the travel restraint from rotating forward during a forward deceleration. Stress analysis showed that the maximum bending stress occurred at the innermost fiber where the U-hook starts to curve around the vehicle's seat. We had originally looked at a steel plate for this purpose but the additional strength was offset by a large increase in overall weight. Softer metals such as aluminum were evaluated, and though were favorable in density, they could not hold the maximum bending moment.

A quick simple release is incorporated in case of emergency. This is accomplished by the attachment of all harness straps to a single easily released buckle. The back assembly is trimmed for sharp objects and projections that could damage the vehicle seats. All edges and bolts are rounded and polished and the main seat belt area is well padded to prevent injury and to prevent undue wear on the seat belt while it is attached to the device. The seat belts of the vehicle (or extra strap for the bus) attach through specially designed holes in the lower portion of the main vertical board.

The lack of significant torso control is the major deficit of standard restraint systems. Additional concerns and health risks of the multiply challenged are equally important design considerations. For instance, the system must have the capability for torso support without causing pressure sores or respiratory difficulties. A provision for cervical and torso support has been implemented to accomplish this. The edges of the LEXAN board are the attachment points for straps that hold special side support bags in place. The overall assembly is a stiff back section padded to provide maximum comfort and pressure sore avoidance. All pads are held in place by multiple two inch wide velcro strips. The torso support side pads mentioned earlier are fixed in position by the same velcro strips. Additionally, all pads are tied to the main frame to prevent loss. The pad covers can be removed for laundering as required. The internal frame of the torso support side pad is actually a one quart plastic water bottle filled with cotton batting. The filled bottle was then wrapped in closed cell foam. When the torso support side pads are properly fixed in position (and held in place by velcro), the torso straps run over the top of the pads and to the shoulder straps of the four point harness. A moderate but not constrictive compressive force is then imparted sideways to the torso to help keep it in position. In the event of a side impact, the pads are designed to absorb a small portion of the impact force before hlunt trauma occurs to the rib cage. The torso support straps are not weight bearing in nature. An outward force is placed on the main vertical strap where the torso strap is looped over to help stabilize the passenger in position. An integral padded head rest/support is included to provide the patient with a comfortable head rest.

The design of this system is intended to be flexible for various environments. This device will be used in situations where the care provider/driver may be working alone. The target weight of the complete assembly was under 20 lbs. Careful selection of materials produced an overall weight of 16.5 lhs. Due to the rural nature of the intended application, the system must be easily repaired on site with commercially available materials and rugged enough to survive daily usage without regular maintenance. The materials chosen will ensure a long device lifetime. The simplicity of design (i.e. few working parts) make the system virtually maintenance free. The use of three different vehicles necessitates the flexihility between vehicles with a short installation and removal time. The U-hooks have been designed to easily fit over the back seat all three vehicles. In order to create a system that would benefit a wide range of adults and children, the system must be adjustable to various sized passengers without major difficulties. The dimensions of the system can accommodate passengers up to 72" in height and 200 lbs weight. The velcro attachment strips provide the capability for installation of custom molded seating material. While the goal of this device is restraint, it also must allow for some freedom of movement for the individual. The harness system allows movement of the arms and movement of the head is also possible. In the event that a wandering hand might unlatch the buckle, a velcro strap has been attached that will cover the buckle.

Durability concerns dictate that the covering material should be removable and machine washable. All of the padding has been covered with an automotive corduroy which is durable, easily obtainable commercially, and machine washable. The covers have been constructed with velcro flaps which eliminates the need for zippers. The device should be weather resistant and not affected by water or mud. The LEXAN frame is easily cleanable with water and the strength characteristics do not degrade with moisture. There is the concern of prolonged UV light exposure which is offset by simply covering the frame with padding. The U-hooks and all of the buckles are constructed of stainless steel and will not corrode under normal and extended operating conditions.

The system is designed to interface directly with the installed vehicle seat belts including a rear seat shoulder belt. In the event that none are present, an additional 2 " wide nylon strap with a 4,000 lb test buckle can be supplied. The extra nylon strap is designed to wrap around the base of the seat frame and follow the same path of the seat belt in the sitting area of the seat.

Finally, the overall strategy is to provide vehicular restraint, but in a manner that does not identify the user as "disabled." Color schemes were chosen that are aesthetically pleasing. The harness system itself resembles that which can be found in the cockpits of high performance aircraft and Indy cars.

Figure 1 shows the general configuration of the device with actual physical dimensions given in Figure 2. It has been shown that a vehicular travel restraint system can be designed that is simple, safe and functional, adaptable to changing environments, provides medically appropriate support and still be comfortable, and is not an eyesore. Issues of three point bending have been avoided by transmitting harness belt and seat belt forces through the same axis; while the U-hooks eliminate the need for any structural or special modification of the vehicle.

## DISCUSSION

The initial development of this device is complete and the target unit cost is less than $300. The next logical step is to locate a facility to perform the dynamic part of the impact simulation as required by Federal law.[2,3] Once past this phase of testing, the final testing phase will include human subjects riding over various terrain to assess total working system operation and comfort. The future development of this device will include a reduction of the harness weight and an adjustable U-hook frame. The latter modification is designed to hroaden the range of vehicles that will accept the device.

The restraint system may be used by the disabled and the non-disabled by simply selecting the appropriate back pad assembly. The concept of standardization of the basic device with the options for customized support for the user should assist in keeping the cost per unit down.

Acknowledgement

The authors wish to express their gratitude to Ms. Pauline Boisselle, OTR, for her technical assistance in measurements of the school vehicles and candid discussions on the realities of transportation of the disabled clients of St. Michael's School.

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Perry B. Kirwan
Department of Chemical, Bio and Materials Engineering
Arizona State University
Tempe, AZ 85287-6006, USA

TABLE 1

MECHANICAL PROPERTIES OF MATERIAL USED

| MATERIAL | $\rho$ (g/cc) | $\sigma_{ult}$ (MPa) | E (GPa) | $\tau$ (MPa) | G (GPa) |
|---|---|---|---|---|---|
| Lexan | 1.2 | 68 | 2.42 | 41.4 | 78 |
| Nylon | 1.2 | 60 | 4 | -- | -- |
| Steel (SS 316) | 7.92 | 860 | 194 | 387 | 75 |

TABLE 2

MECHANICAL ANALYSIS

| STRESS TYPE | $\sigma_{all}$ (MPa) | $\sigma_{ult}$ (MPa) | $\tau_{all}$ (MPa) | $\tau_{ult}$ (MPa) | F.S. |
|---|---|---|---|---|---|
| $\sigma_{nylon}$ | 18.41 | 60 | -- | -- | 3.26 |
| $\tau_{Lexan}$ | -- | -- | 1.15 | 41.4 | 36 |
| $\sigma_{b,Lexan}$ | 11.3 | 68 | -- | -- | 6 |
| $\sigma_{b,Steel}$ | 426.0 | 860 | -- | -- | 2 |
| $\tau_{Steel}$ | -- | -- | 94.3 | 387 | 4 |
| $\tau_{bolt}$ | -- | -- | 62.1 | 74.5 | 1.2 |

F.S. = FACTOR OF SAFETY

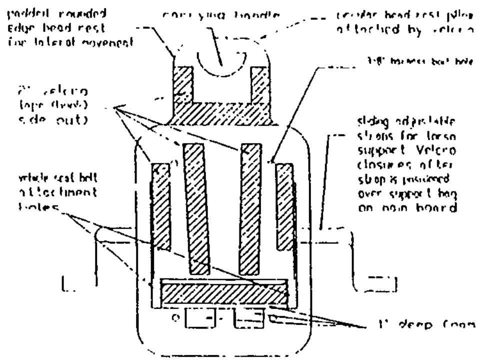

Figure 1. General Configuration of Travel Restraint Sys. (TRS)

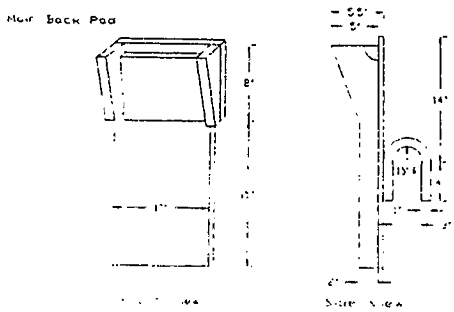

Figure 2: Physical dimensions of (TRS)

# THE INTELLIGENT MICROWAVE OVEN

Mark R. Schmeler OTR/L & Myron J. Deputat BSEE
Center for Therapeutic Applications of Technology
University at Buffalo
Buffalo, New York USA

## INTRODUCTION

The Intelligent Microwave Oven is a device that will simplify and automate microwave cooking for individuals with cognitive and physical disabilities who have safety problems preparing meals over conventional open heat. This device makes use of a bar code and optical scanner to identify and cook specified foods in a microwave oven for given times and heat levels. Essentially the process of multiple key entries to program a conventional microwave oven are eliminated. An initial prototype of the device has been constructed by interfacing an off the shelf microwave oven with a hand held computer and bar code scanner. This device is capable of reading the UPC code on the food package, locating the code in a database, and associating the code with a set of cooking instructions. The cooking instructions are then sent to the microwave's control panel to cook the food.

The UPC code, used with this design project, is a twelve digit individual identification number that is assigned by the Uniform Product Code Counsel and placed on virtually all consumer products sold in North America[1]. The first six digits of the code identifies the company and the remaining six represent the company's product. The UPC bar code was developed by the grocery industry to increase speed and efficiency at the checkout counter. The code itself gives no immediate information on the name or the price of the product. To obtain this information, the code has to be searched and matched in a database[2]. For this reason the UPC code will not provide any immediate information to the microwave oven regarding cooking instructions. The cooking instructions have to be retrieved from a database thus requiring the use of a microcomputer to construct a prototype of the Intelligent Microwave Oven.

## BACKGROUND

Safety in meal preparation is of ultimate concern for persons with disabilities including those associated with aging. Ovens and ranges have been identified as the consumer products second most involved in injuries in the home environment after bathtubs and showers[3]. Inability to safely prepare ones meals in the home often results in having to seek alternative living arrangements.

A microwave oven is a good alternative means of safe and efficient meal preparation for people with disabilities. The chances of burning oneself is greatly reduced when using a microwave oven versus a conventional range or stove. Microwave cooking also reduces the amount of energy expended by the person as little preparation and cleaning up is required in the process.

With the recent advancements in technology, microwave ovens have become multi-functional. In many cases, the multi-functions of the appliance have resulted in a complex control panel that requires a multitude of keyed data input in order to perform desired functions. It would appear that the complexity of programming a microwave would only hinder its use by individuals with disabilities and the general public. This is noted by the first author who in his work with people in the elderly population has found them to be overwhelmed by the complex steps involved in setting the controls. It would seem that success in teaching a person to program a microwave depends largely on the person's amount of familiarity with the device in the past.

The control panel of a microwave oven is not only complex but also difficult to read for those with visual impairments. The symbols and characters on the various keys are often small and placed on a poorly contrasted background. Tactile discrimination of the keys is often impossible especially when the control panel is a flat surface with no ridges or raised surfaces to outline them. Individuals with visual impairments also might be unable to read the cooking instructions printed on a food package as it is often very small. At the same time, determining the contents of a food package is difficult especially if different foods have similar packaging.

An alternative means of access to meals for those who are unable to prepare them themselves is through the Meals on Wheels Program. At present in the United States, the Meals on Wheels program is responsible for providing over 350 million meals to people annually[4]. Reports from the National Association of Meal Programs, the organization that represents and advocates the Meals on Wheels Program nationally, indicate the demand for these services can only increase with an aging population while financial resources decrease. They further state that individual meals programs on average have a waiting list of 80 candidates in need of these services with some that have a waiting list as high as 300. The largest cost involved in providing this service is reported to be the transportation of a hot meal to a person's home on a daily basis.

The use of a microwave oven could allow for delivery of a supply of frozen meals to a person's home on a weekly basis thus reducing delivery cost and expanding service availability to more people. This process would obviously take away the daily contact one receives from a delivery person however, it could be replaced by more quality contact provided by other organizations such as the local church.

From this background information and the problems described above, the Intelligent Microwave Oven was conceptualized and a prototype was built. The goal of the project was to devise a device that would allow for easier use of a microwave oven by those with disabilities. The use of a UPC bar code, optical scanner, and interface would allow a person to automatically set the microwave oven. Use of bar codes to control a microwave oven has been attempted in the past[5,6], however no device is currently available on the consumer market. An added feature to this design will incorporate the use of speech output which will provide information about the contents of a food package as well as instruction about the cooking process for individuals with visual or cognitive impairments.

## METHODS

The development of the Intelligent Microwave Oven was conducted in three stages. These development stages involved interfacing the PSION Organiser II with the microwave control panel, programming the PSION Organiser II[7] to decode UPC bar code information using the Nippon Denso[8] hand held CCD scanner, and development of a voice synthesis board.

To complete the first stage of the project design, the development of an asynchronous communication control board was required to interface the PSION Organiser II with the microwave control panel. This board converted an information stream from the PSION Organiser II into a series of control signals, which were then used to simulate actual operation of the microwave control panel. This then allowed for a program from the PSION Organiser II to enter a series of commands on the control panel.

In the second stage of the project, the Nippon Denso hand held CCD scanner was attached to the PSION Organiser II and used to read UPC bar code information. The bar code information obtained by the hand held scanner was used to select between different control programs for the microwave control panel. In this way cooking recipes could be prepared for particular products, and be identified by their UPC code.

In the final stage, a speech processor board was designed as a feedback device for the visually or cognitively impaired. The design of this device required a thorough investigation of current speech synthesis technologies. During the investigation of different speech synthesis technologies, several prototype speech boards were developed. After final evaluation of the prototype boards, the board with the best sound quality, and largest vocabulary was interfaced to the PSION Organiser II.

Further development of the Intelligent Microwave Oven is currently under way. Upon completion of the current research the PSION Organiser II will be replaced with a custom control module, and an alternative scanning technology will replace the Nippon Denso hand held CCD scanner.

## RESULTS

An initial prototype of the Intelligent Microwave Oven has been completed and plans for field testing are underway. A second prototype will be developed in the near future that will eliminate the need for the PSION Organiser II as an interfacing device thus reducing costs. Collaborations with the National Association of Meal Programs and Results-Technology are also progressing to study the feasibility of using this device with the Meals on Wheels Program.

## SUMMARY

Microwave ovens have been described as a safe and easy alternative means of meal preparation for people with disabilities. With advancements in technology, microwave ovens have become multi-functional and complex. This complexity has in many cases made programming the appliance a complicated task. The Intelligent Microwave Oven has been described as a potential design solution to solve these problems. This is done by automating the task of keyed data entry required to set a microwave oven to perform any given function. This has been demonstrated through the design of a prototype that interfaces a microwave oven with a bar code, optical scanner, hand held computer, and speech output device.

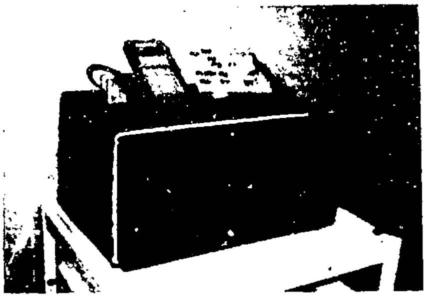

Photo 1: Working Prototype of the Intelligent Microwave Oven with hand held scanner and microcomputer.

## ACKNOWLEDGEMENTS

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8. Dynasys Technologies Incorporated, Clearwater, FL.

Mailing Address;
Mark R. Schmeler
CTAT / UB
515 Kimball Tower
Buffalo, NY 14214

# Author Index



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