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ABSTRACT

Papers in this conference proceedings focused on the progress and potential of assistive and rehabilitation technology for individuals with disabilities and ways that RESNA members could help these ideas to be realized. Presentations were delivered on the following topics: (1) service delivery and public policy issues; (2) personal transportation; (3) augmentative and alternative communication; (4) drooling; (5) quantitative assessment; (6) special education, including telephone technology for sensory integration, assessing predispositions to technology use in special education, explaining legal ramifications of the appropriate application of assistive technology in the Individualized Education Program, voicing dyslexia remediation, speech evaluation of habilitation training of children with hearing impairments, and innovative interagency collaboration; (7) technology transfer; (8) sensory aids; (9) wheeled mobility and seating; (10) electrical stimulation; (11) computer applications; (12) rural rehabilitation; (13) assistive robotics and mechatronics; (14) job accommodation and employment issues; (15) information networking; (16) gerontology; (17) international appropriate technology; (18) Easter Seal Student Design Competition; and (19) Whitaker Student Scientific Paper Competition. Presentations include references. (CR)

RESNA '94

June 17-22, 1994
Nashville, Tennessee

Tuning in to the 21st Century through Assistive Technology Listen to the Music

MUSIC CITY
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PRODUCTIVITY
INDEPENDENCE
INCLUSION
RECREATION
ADVOCACY
EMPOWERMENT
EMPLOYMENT
EDUCATION

PROCEEDINGS

PROCEEDINGS
of the
RESNA '94
Annual Conference

Tuning in to the 21st Century Through Assistive Technology

Listen to the Music

June 17-22, 1994

Nashville Convention Center
Nashville, Tennessee

Mary Binion
Editor

Randall Dickman
Jan Coatney
Conference Co-Chairs

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Foreword

On behalf of the RESNA Board of Directors and this year's RESNA Local Committee we welcome you to Nashville, Home of the Grand Ole Opry, for the 1994 RESNA Annual Conference.

Once again, the conference promises to provide a unique opportunity for consumers, vendors, service providers, and researchers from all over the world to meet together and exchange information about assistive technology, present and future. From the (serious) paper presentations to the (fun) Dance Nite, the Conference offers the attendees a number of opportunities to share information, renew old friendships, and make new ones.

We wish to thank everyone who worked to make this year's conference a success. We particularly wish to recognize Susan Leone for her enthusiasm, expertise, and tirelessness in monitoring the hundreds of details necessary to bring the conference together.

Have a great conference. See you again next year!

Jan Coatney and Randall Dickman
RESNA '94 Conference Co-Chairs

Gregg C. Vanderheiden
RESNA President

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Preface

Welcome to RESNA '94 "Tuning in to the 21st Century through Assistive Technology-Listen to the Music." As we prepare to become involved in this conference, let us remind ourselves about the symphony of assistive and rehabilitation technologies and the appropriateness of this theme.

We are the instruments. The assistive and rehabilitation technologies are our tools on which to play. They are the way that we bring success to ourselves and those we serve. We are the voice in the assistive technology song.

We are the composers. We are writing the elements to define who we are. We are creating the music that awakens new ideas. With the changes that are occurring in the assistive and rehabilitation technology field, we are searching for the pivotal moment, when the right choice will bring us closer to achieving our goals.

We are the musicians. We tailor our ideas successfully to meet the conditions of the changing world. Sometimes we improvise. The key to our success is that we reach out, extend our music to it's boundaries, and then do it over again. We work together to extend ourselves and our talents.

We are the conductors. We interpret what has been written. We take a group of divergent individuals and blend their talents and skills to create a symphony orchestra. We determine the emphasis-the crescendo. We are constantly seeking better ways, and we are not intimidated.

We have many reasons to celebrate and many notes to sing. Some of us respond better to the soft intonations, while others prefer the rhythmic, pulsating beat. Now you must chose to write and play your songs. I hope this concert provides you with an incubator for new ideas, an opportunity to develop action plans, and a time to build new coalitions. Enjoy!

Mary Binion
Chair, Scientific Program and Special Interest Groups

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State of Tennessee Department of
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University of Washington
Vanderbilt University
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SIG-09: Wheeled Mobility and Seating

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SOCIAL WORK AND THE INTERDISCIPLINARY NATURE OF ASSISTIVE TECHNOLOGY

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ABSTRACT

Assistive technology has experienced rapid changes in philosophy and practice, from institutionalization to full inclusion and from isolation to independence. As a result professionals from both technology and human services are a part of an interdisciplinary team facilitating this independence. Where is Social Work's place in the Assistive Technology interdisciplinary team? It can be an empowering force, one which links the consumer and the interdisciplinary team with the resources to better achieve personal independence of the people with disabilities. They can do this with a knowledge base unique to the social work profession. The effects of the social environment on the consumer's ability and willingness to use their assistive technology can be addressed by the interdisciplinary team more effectively with the addition of the social work profession.

BACKGROUND

The last decade has witnessed monumental changes not only in the types of services provided to people with disabilities but the basic philosophy which reflects the values that we place on people with or without disabilities. Rather than tolerate diversity we are celebrating it with a philosophy encompassed in the terms "normalization" and "inclusion." The philosophical changes that have occurred in disabilities services and practices are well reflected in the language and provisions of recent legislation. Past legislation and the more recent Americans with Disabilities Act have all attributed to consumer responsiveness, consumer directedness, consumer participation and decision- making, and the right to access public services. As a result, technology is utilized to assist people in becoming independent. The availability of sophisticated information, down from the professional to the end user, coupled with increased concern for individuality, independence, and participation has created a paradigm shift in the disability field. Perhaps the most important change has come in the role of the consumer from a passive, grateful recipient to an active participant in determining need, making intervention decisions, and commitment.

Assistive technology is a vital interest to the family, both nuclear family and extended, and society in general. The role of technology and disabilities affect our service institutions, hospitals, schools, rehabilitation agencies, and job placement as well. These are issues that the rehabilitation engineer, the supplier, and the clinical professions have not had to deal with in the past and have had little training or experience in.

Assistive technology services is truly interdisciplinary and rather than expanding each clinical or technical discipline to include expertise in the social, environmental, and societal implications of technology we should reach out to those professions that have traditionally addressed these issues, such as social work, social psychology, family development, and community organization.

It is with this premise that the Assistive Technology services at Utah State University was prompted to establish an interdisciplinary careers program. Included in this program the first year were the technological professions of assistive technology, engineering, and computer science; and the human service professions of psychology, communicative disorders, special education, and occupational therapy. The profession of social work was added the following year in an attempt to expand the teams effectiveness.

STATEMENT OF PROBLEM

As we have mentioned earlier, the utilization of advanced technology can help make the lives of people with disabilities considerably more independent. An interdisciplinary team is the most effective model to facilitate this independence. There has been a great increase in the information that is available to both the professional and the consumer. The consumer is now an active participant in this decision-making process. An interdisciplinary team works together with the consumer and shares information to better provide for the consumer's needs.

SOCIAL WORK ROLES

In the Assistive Technology at Utah State University we have found that just using technical people from different disciplines is falling short of reaching the goal of a fully functioning interdisciplinary team. In order to facilitate the independence of consumers, we must be more aware of the effects of their social environment on their ability and willingness to use needed technology. Adding team members from the social sciences, such as social work, facilitates a move toward understanding better the consumer in their environment.

The problem to date has been that the bigger focus has been on the technical independence for the consumer. We have yet to fully understand the reciprocal transactions that take place between the consumer and the many systems in his/her environment that make independence complete. To achieve our aspirations in this regard we need to find a way to incorporate this needed sensitivity into the interdisciplinary team.

APPROACH

Our premise is that the social work profession contributes to the interdisciplinary nature of assistive technology because it is a multi-skilled profession. Social workers are knowledgeable in three levels of intervention including micro (individual), mezzo (families, groups, and agencies), and macro (communities and social policy). The social work profession is characterized by their method and specific knowledge base in human behavior and the social environment. A social systems model, in part, is where our knowledge and skills are derived. This knowledge building is focused on the interplay between the person and his/ her environment. The concepts and techniques of an empowerment approach can promote a person interacting more effectively in his/her environment.

The empowerment approach is a process for increasing personal, interpersonal, or political power so that consumers can take action to improve their life situations. It allows the consumer to develop a sense of personal power, and ability to affect others, and an ability to work with others to change social systems. Empowerment techniques used to increase independence include: (1) accepting the consumer's definition of the problem, (2) identifying and building upon existing strengths, (3) teaching specific skills, (4) mobilizing resources in the consumer's environment, and (5) advocacy support groups.

DISCUSSION

The interdisciplinary team functions such that although each member may have a different set of skills to contribute, there is an attempt to thoroughly share the information during assessment and post planning, and that a consensus is obtained in order for the team to function as a whole. Further, there is generally a case manager who is qualified to summarize, extricate and convey findings to the client/family/agencies and provide recommendations for therapies or for providing solutions to specific problems. It is in this role of either case manager or consultant that the social worker could play a salient role. A social worker, using an empowerment approach, can make a unique contribution in the following three ways: (1) focusing on funding issues which entail facilitating families in making use of community resources, including services and financial assistance; (2) a liaison role keeping lines of communication open between agencies, family, and client; and (3) the worker can also work with agencies, local communities, and legislators to make technology more available to clients. In addition, social workers along with other professionals, can provide counseling to help clients adjust to their disability and to rehabilitation programs; counsel with the family to help them adjust; take social histories about the client's family background and present status; and do discharge planning.

The monumental changes in the types of services provided people with disabilities and the basic philosophy of these services along with the changes in policy have created a great need to better understand the client in their environment. Just as the technology is becoming more sophisticated so are the reciprocal effects of the consumer and the environment. The interdisciplinary team approach has helped considerably with these issues. As we include the social work profession as a part of the interdisciplinary team it will function even more effectively.

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TECH POINTS: Enhancing the Use of Rehabilitation Technology in Vocational Rehabilitation Agencies

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ABSTRACT

TECH POINTS is a rehabilitation technology management and training strategy developed for use in vocational rehabilitation agencies funded by the United States government. Under development for field trial, TECH POINTS is designed to provide rehabilitation counselors with an easy to follow desk reference suggesting when and how they should consider use of rehabilitation technology with their clients.

BACKGROUND

The Center for Rehabilitation Technology Services (CRTS) received a five year research grant from the National Institute on Disability and Rehabilitation Research. The focus of this grant is on rehabilitation technology applications in Vocational Rehabilitation (VR) Agencies. The TECH POINTS model will be used as the basis for an intervention study assessing the efficacy of TECH POINTS as a strategy to integrate technology into the VR process.

Rehabilitation technology efforts in vocational rehabilitation (VR) agencies have concentrated on implementing technology service delivery capabilities within the agency or through use of outside service providers. These efforts have helped make rehabilitation technology services more available, but they haven't always shown how the use of technology resources and services could, or should, be integrated into the rehabilitation process. Even with the mandate to include rehabilitation technology services as part of the vocational rehabilitation process since 1986, these services are still not effectively integrated into regular case management activities (Langton, 1991).

Access to rehabilitation technology services is influenced significantly by the knowledge and capability of vocational rehabilitation counselors to use these resources and services with individuals on their caseloads (Phillips, 1992; Rice, 1990).
Improving the integration of rehabilitation technology into the VR case service process was the objective of project activities initiated by the Center of Rehabilitation Technology Services. A conceptual model, TECH POINTS, was developed to determine when and where technology resources should be utilized in the VR process tion (Langton, 1991). This model identified nine specific points within the rehabilitation process where the use of technology should be considered.

STATEMENT OF THE PROBLEM

The original TECH POINTS model was well received as an effective illustration of how rehabilitation technology services could be integrated into the VR process. Further development revealed some concern with the expectations of the rehabilitation counselor and the compatibility that the system would have with different VR agency structures. It was determined that in order for TECH POINTS to be an effective strategy, the system had to be designed for use within any state-federal vocational rehabilitation program, with only a minimal amount of paperwork or procedural changes.

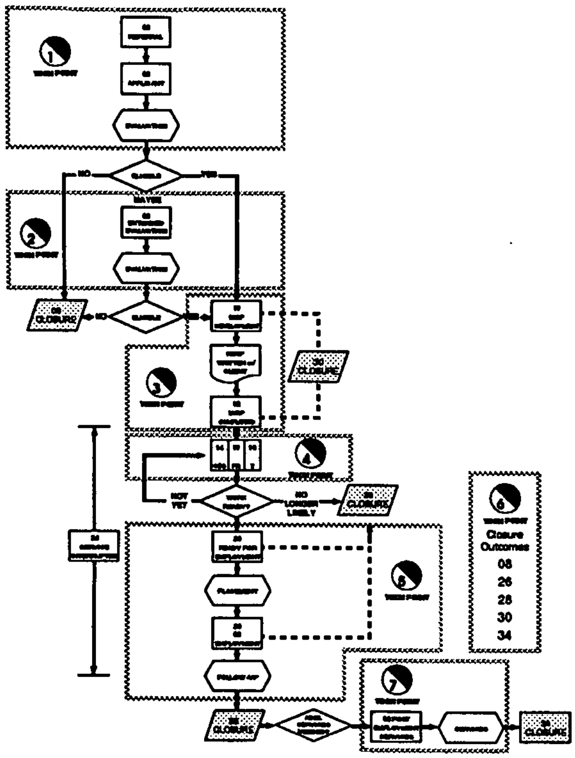
Preliminary work with the model suggested that modifications were needed to:

1. Better integrate the TECH POINTS into the VR case service process,
2. minimize the number of TECH POINTS,
3. make modifications to conform to the 1992 Rehabilitation Act Amendments.

APPROACH

Working with a study group of rehabilitation case management staff and technology specialists, the original model was modified to better conform to the VR case service process. The original nine TECH POINTS were reduced to seven, with adjustments made for changes created by the 1992 Rehabilitation Act Amendments. Still employing a series of "critical junctures" in the rehabilitation process, TECH POINTS now provides the vocational rehabilitation staff with easy to follow guidelines for systematic consideration of rehabilitation technology services for VR clients.

Figure One illustrates the seven TECH POINTS within the overall vocational rehabilitation process.



Since TECH POINTS is based on the existing rehabilitation process which is generally consistent throughout all VR agencies, it should integrate rehabilitation technology services into regular case service activity. The revised TECH POINTS model is a continuous process which begins with consideration of rehabilitation technology needs that a prospective client might have and systematically follow that individual throughout their rehabilitation process.

TECH POINTS

The following information briefly describes the seven TECH POINTS. Reference is given to the case status codes numbers, such as (02), which are in common use by VR agencies.

TECH POINT 1 *Referral/Application*

(00,02)
Initial technology-needs screening of all applicants for VR services, which includes completion of a rehabilitation technology needs profile for those applicants who use technology or where a technology-related need has been identified.

TECH POINT 2 *Extended Evaluation*

(06)
Suggestions given for including rehabilitation technology services in comprehensive assessment and vocational evaluation services, with use of a rehabilitation technology assessment recommended for individuals with identified technology-related needs.

TECH POINT 3 *Plan Development*

(10,12)
Suggested approaches on how to include appropriate use of rehabilitation technology to achieve vocational goals as part of the individually written rehabilitation program (IWRP).

TECH POINT 4 *Services*

(14,16,18)
Tips for including appropriate use of rehabilitation technology in all services, including counseling and guidance, physical restoration and vocational and work adjustment training.

TECH POINT 5 *Placement/Follow-Up*

(20,22)
Addresses potential need for job accommodations to assist in performing "essential functions" of the job. Includes ways to use rehabilitation technology with job development and in identifying feasibility of accommodations.

TECH POINT 6 *Closure Points*

(08, 26, 28, 30, 34)
Review of successful and unsuccessful VR closures to ensure that appropriate consideration was given to the use of technology resources and services.

TECH POINT 7 *Post-Employment*

(32)
Identification of rehabilitation technology interventions needed to maintain employment.

Technology Interventions

Without a background in rehabilitation technology services, most VR counselors have difficulty determining what rehabilitation technology services an individual might need. Within the TECH POINTS structure, descriptions are provided of possible "technology interventions" which could be appropriate to consider.

Technology interventions include: ■ technology consultation, ■ vocational evaluation accommodations, ■ rehabilitation technology assessment, ■ home/adapted living accommodation, ■ school/training accommodation, ■ job/work site accommodation and ■ job development/feasibility studies.

DISCUSSION

The revised TECH POINTS structure is expected to provide the vocational rehabilitation counselor with an easy to follow guide for considering the use of rehabilitation technology with all clients. Integrating the consideration of rehabilitation technology into day-to-day case service practice must occur if these services are to be effectively utilized.

TECH POINT should help to de-mystify rehabilitation technology and enable counselors to work more closely with technology service delivery specialists. The VR counselor is the key for consumers to be able to access rehabilitation technology services. Effective use of rehabilitation technology depends on the counselor and consumer working together to recognize the potential benefit from these services. The importance of initial contact at point of referral and the counselor's continuing role in coordinating all rehabilitation services makes it essential that counselor's have a basic awareness of rehabilitation technology and have direct access to rehabilitation technology resources and services.

Implementation of the field testing of the TECH POINTS model in selected VR agencies will begin in mid-1994 and continue for approximately two and one-half years. Results of this study will be made available through CRTS.

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ENGINEERING SERVICE PROVISION FOR VOCATIONAL REHABILITATION IN TENNESSEE

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Abstract

The University of Tennessee, Memphis, Rehabilitation Engineering Program (UTREP) has been working together with the Tennessee Division of Rehabilitation Services (DRS) to provide job accommodation evaluation and support services for vocational rehabilitation clients throughout the state. Through a pre-paid contract renewed each year with the agency, the program has been able to establish two satellite sites to provide service delivery in other areas of the state. By maintaining responsibility for training staff members at other sites and by reviewing work performed at those sites, UTREP is working with DRS to give vocational rehabilitation clients across the state equal access to rehabilitation engineering services.

Background

In 1989, DRS approached UTREP to establish a contract for the provision of job accommodation services to DRS clients. The original agreement called for services to be performed only in west Tennessee. In each year since 1989, DRS has renewed its contract with UTREP and has worked with UTREP to improve service delivery to its clients.

Approach

Services are provided through a pre-paid contract, renewed yearly, known as the "Rehabilitation Engineering Services Project." Providing services through a contract rather than through a fee-for-service arrangement benefits DRS counselors and clients because counselors do not have to wait for authorization before referring clients to project agencies.

Because Memphis is located in the southwest corner of a state that is over 400 miles wide, UTREP could not reasonably provide rehabilitation engineering services for the entire state, even with the use of a mobile laboratory. Instead, UTREP and DRS selected the model of establishing at least one satellite site in each of the three grand divisions of the state (west, middle, and east). The initial satellite agency, the STAR Center in Jackson, Tennessee, was established in July 1990. Though Jackson also lies in the west division of the state, staff members of the STAR Center provided the project with much-needed expertise in adaptive technology for persons with visual impairments. The East Tennessee Special Technology Access Center (ETSTAC) joined the project as a satellite agency in July 1993 to serve the east division of the state.

As the lead agency for the project, UTREP is responsible for training staff members at each satellite agency. Training includes topics such as the responsibilities of each project staff member under the contract, the operation of adaptive equipment, and evaluation and report-writing techniques. UTREP also provides technical expertise and performs product investigations for staff members as needed. On occasion, UTREP staff members may travel to other sites to assist in evaluations or other service provision. UTREP is also responsible for reviewing the evaluation reports from each site, ensuring that clients of each project agency receive the same recommendations as they would from any other project agency.

The following services are currently available to DRS counselors and clients through the project:

- Consultation. Counselors may refer clients for preliminary assessments to assist the counselor in determining if the client could benefit from pre-paid services available through the contract.
- Evaluation. Counselors may refer clients for formal assessments for assistive technology. Each evaluation results in a formal report describing the evaluation process, the items recommended as a result of that evaluation, and a justification for the purchase of each of those items. The report also includes information on where each item can be purchased, and three or more vendors for each item for which bids must be received. The evaluator is always careful to avoid the presumption that DRS will purchase all or even any of the items recommended, because counselors often work with employers and with the clients themselves to determine responsibility for purchase.
- Installation. Project staff members perform installation services when appropriate. Installation services are most commonly needed when a computer system has been purchased for a client.

- Training. Project staff members train clients in the operation of any equipment, non-adaptive or adaptive, that they receive. The training may require only one session that takes place at the time of installation; however, when clients receive more sophisticated equipment (such as what is required to allow the client to establish a home-based desktop publishing business), the training may involve repeated visits to the client's home or place of employment.
- Support. Project staff members provide support over the phone for questions clients may have regarding the operation of non-adaptive or adaptive technology that they have acquired through DRS. If problems cannot be resolved over the phone, project staff members will travel to the client's home or place of employment over a period of weeks or months.
- Lending library. A survey of DRS counselors in 1990 (1) showed that, after counselors received a report detailing recommendations for a computer system, the average delay before delivery of the system was $5^1/_2$ months. DRS has since worked with UTREP to set up a lending library of computer systems, including adaptive access software and hardware, that can be provided to DRS clients as soon as the regional supervisor grants approval for the purchase of their systems. The lending library is currently being expanded to include other types of technology, such as TDD devices and environmental control units.

Each agency tries to be as consumer-responsive as possible. During each evaluation, clients are encouraged to share freely about preferences they may have for equipment or software, and about problems they may be encountering other than those that led to the referral for services by their counselor. When clients call regarding problems with equipment or software that cannot be solved over the telephone, staff members are almost always able to re-arrange their schedules to visit the clients on-site within one week. When DRS requested that evaluation reports be sent to the counselors as soon as possible, UTREP staff members redesigned the narrative portion of the evaluation report to reduce the time required to prepare each report.

Discussion

It is important for each client of the Division of Rehabilitation Services to have, whenever possible, equal access to assistive technology services to help them gain employment. By establishing sites around the state that provide consumer-responsive services as quickly and as uniformly as possible, DRS and UTREP have taken great strides toward achieving that goal.

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KNOWLEDGE OF ASSISTIVE TECHNOLOGY IN SPINAL CORD-INJURED INDIVIDUALS IN KENTUCKIANA

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ABSTRACT

Sustaining a spinal cord injury results in significant impairment in all areas of life. Specifically, dependency in the areas of activities of daily living, work/school and leisure results in the loss of control over the major functions of life. One approach the occupational therapist may use to address these areas is to provide assistive technology. The purpose of this study was to determine the knowledge of spinal cord-injured individuals residing in Kentuckiana regarding assistive technology. A mail survey of 84 persons with quadriplegia determined the types of assistive technology the individuals were exposed to, whether evaluation was completed to determine device selection, was training provided in the use of obtained devices and who introduced these devices to the individual. The results indicated that the respondents expressed uncertainty/agreement when asked if they had received proper evaluation and disagreement and uncertainty when asked if they felt they had received adequate assistive technology services. The respondents were in agreement that they had been properly trained to utilize equipment they owned.

BACKGROUND

The treatment of the individual with SCI is a complex task. Regardless of the person's level of injury, the rehabilitation of the SCI individual will include the services of a variety of professionals. Areas that these professionals may address include training in activities of daily living, strengthening activities, communication, mobility, exploring avocational and vocational interests and skills and providing assistive technology to support these activities. Assistive technology is defined as "any piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities" (Technology-Related Assistance for Individuals With Disabilities Act of 1988).
Due to the rapid development of new technologies, possessing adequate knowledge in the provision and use of assistive technology for persons with SCI is a difficult role for professionals to fulfill properly. While professional curricula are now addressing assistive technology, there remains a large number of professionals who may not have the knowledge to properly meet the role of providing assistive technology to persons with SCI.

The purpose of this study was to conduct a survey of users of assistive technology devices to determine their knowledge regarding assistive technology, where they received this information and what training and services they received. Investigation of the problem served to identify those areas in which persons with SCI currently require the greatest assistance.

RESEARCH QUESTIONS

1. Are persons with quadriplegic SCI in Kentuckiana receiving adequate high tech assistive technology services?
2. Are persons with quadriplegic SCI in Kentuckiana who utilize high tech assistive technology being evaluated properly for device selection?
3. Are persons with quadriplegic SCI in Kentuckiana receiving adequate training in the use of devices they have received?
4. Who in Kentuckiana is making high tech assistive technology device recommendations?

METHODOLOGY

The research design used for this study was survey research. The information for the survey was gathered through the use of a mailed questionnaire. The instrument used to collect data was a questionnaire developed by the author. The questionnaire consisted of open-ended, closed-ended, contingency questions and attitudinal scales. The purpose of the questionnaire was to determine the types of assistive technology the individual has been exposed to, whether evaluation had been completed to determine device selection, was training provided in the use of obtained devices and who introduced these devices to the individual.

The subjects included individuals with complete or incomplete quadriplegia who had received rehabilitation services at a rehabilitation hospital in Louisville, Kentucky.

RESULTS

Thirty-six or 51% of the 70 subjects returned the questionnaire. Demographic information revealed that the average age of the respondents was 37.1 years. The respondents level of injury varied from C3 to C7 with a majority (20%) of the respondents demonstrating an injury at the C6-7 level. The demographic information also revealed that 82% of the respondents indicated that they had not received information regarding funding for assistive technology devices. All of the 18% that had received funding information, had obtained this information from a vocational counselor.

Questions one through four asked the respondents to identify assistive technology devices they had tried out or owned and which rehabilitation professional introduced them to or recommended that they purchase each device. Devices the respondents had tried out are displayed in Table 1. Physical therapists (76%) were the professionals responsible for the majority of introductions to power wheelchairs with equipment vendors (24%) listed second. Occupational therapists, vocational counselors and others were equally identified (31%) as the professionals responsible for introduction to the computer. Fifty percent of the respondents who had tried out driving aids indicated that vocational counselors had introduced them to these devices.

Table 1
Assistive Technology Devices Tried Out

Device	n	%
Power Wheelchair	25	83
Computer	16	53
Driving Aids	12	40
Environmental Control Unit	3	10
Electric Page Turner	1	3

Distribution of the devices owned by the respondents is presented in Table 2. Physical therapists (65%) were the professionals identified most frequently as being responsible for recommending purchase of the wheelchair, with equipment vendors (15%) and other (15%) being second. Vocational counselors (44%) and rehabilitation technologists (33%) were cited as those most responsible for recomendation of driving aids. Of the seven persons that had purchased a computer, five (71%) of the respondents indicated that others were most responsible for recommending there purchase. Others included family, employer, psychologist and themselves.

Table 2 also lists devices the subjects owned and were trained to use. Physical therapists (69%) were the professionals most identified as being responsible for providing wheelchair training. Vocational counselors (56%) were identified most frequently as the professional providing training in the use of driving aids. Other (66%) was identified most frequently as the professional responsible for the provision of training in the use of computers. Occupational therapists were most frequently identified for providing training in the use of environmental control units (66%) and electric page turners (100%) respectively.

Table 2
Numbers of Respondents Trained to Use Assistive Devices They Own

Device	Number Who Own Device	Number Trained to Use Device	% Trained
Power Wheelchair	20	16	80
Driving Aids	9	9	100
Computers	7	3	43
Environmental Control Units	3	3	100
Electric Page Turner	1	1	100

The respondents were asked to identify the rehabilitation professional they felt had been the most helpful in providing assistive technology services. Physical therapists were identified as most helpful, occupational therapists were listed next in importance, and vocational counselors were listed third. Other and rehabilitation technologists were also mentioned.

To ascertain the respondents views towards assistive technology and the services they had received, a 5-point Likert-type scale was used. One was strongly disagree and 5 was strongly agree. Results are shown in Table 3.

Table 3
Responses to Attitudinal Scale Questions

Questions	Mean Score
I feel that I have a good understanding of how assistive technology can help me.	3.6
I feel I was properly trained to use all the assistive technology devices that I own.	4.0
I feel that I was properly evaluated for all the assistive technology devices that own.	3.6
Overall, I feel that I have received adequate assistive technology services.	2.8
Overall, I feel that assistive technology has been helpful to me.	3.6

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DISCUSSION

The results of the study are limited due to the respondents' diagnosis of quadriplegia, the small sample size, limited knowledge of the respondents functional status and the fact that they represent a small geographical area. Because of these factors, the ability to generalize the findings beyond Kentuckiana or according to level of injury is not possible.

The large number of respondents who indicated that they had not received information regarding funding indicates a strong need for rehabilitation professionals to provide this information. Also, the fact that the vocational counselor was the only professional cited as providing funding information indicates a need on the part of all professionals to become more knowledgeable and active in this area.

The power wheelchair was identified most frequently as the assistive technology device that the respondents had tried out, owned and been trained to use. This information is not surprising in that the wheelchair serves as the primary source of mobility, postural support and is frequently covered by insurance. The fact that the physical therapist was identified as the person most responsible for introducing, recommending purchase and providing training for this device may serve as the reason why the physical therapist was viewed as the professional most helpful in providing assistive technology services.

The computer was the second most frequently identified device that the respondents had tried. Less than one-fourth of the respondents indicated that they owned a computer. Related to this was the finding that others were the persons most cited for recommending purchase. This suggests that computers are being used as treatment tools, but are not being pursued as a possible means for increased independence.

Physical therapists, occupational therapists and vocational counselors were the professionals listed as being most helpful in providing assistive technology services and as the professionals responsible for recommending devices and providing device training. This indicates that these professionals need to make a concerted effort to maintain or increase their knowledge in the area of assistive technology services. The fact that rehabilitation technologists were seldom listed indicates a need for increased involvement by this professional group in the provision of assistive technology services.
The most striking aspect of survey findings were the results of questions utilizing the Likert-type scale. The 2.8 mean score in response to the statement asking if they had received adequate assistive technology services indicates that they perceive that they have not received adequate services. This information coupled with the 3.6 mean scores in response to the statements regarding having an understanding of assistive technology, the belief that they received proper evaluation and the belief that assistive technology has been helpful to them suggests a need for improving the provision of assistive technology services. It may also indicate that more thorough patient education is needed in regards to what assistive technology may be beneficial or not practical for the potential users. It is noted that the data strongly suggest that proper training is being provided for those devices which the respondents receive.

Reviewing the research questions of this study indicates that assistive technology services provided to persons with SCI in Kentuckiana could be improved. The study also suggests that persons with SCI in Kentuckiana are being properly evaluated for and trained in the use of assistive technology devices. Finally, physical therapists, occupational therapists and vocational rehabilitation counselors are the persons most responsible for assistive technology recommendations.

It is recommended that this study be replicated for the entire state of Kentucky in order to generalize the findings. Further research is suggested to identify the needs of all persons who utilize or may benefit from assistive technology.

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PROJECT IMPACT: DEVELOPMENT OF A STATEWIDE SERVICE DELIVERY MODEL THROUGH LOCAL CAPACITY BUILDING

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ABSTRACT

Project IMPACT represents a partnership among three organizations to improve and expand access to assistive technology services for North Carolinians with developmental disabilities. The project's overall purpose is to build assistive technology service delivery capacity in North Carolina. IMPACT operates under the following four goals: 1) develop a comprehensive array of assistive technology services by linking existing programs, 2) expand assistive technology service delivery capacity statewide, 3) provide training to consumers, families and professionals on assistive technology use, and 4) establish networks for information exchange and support among families, consumers and professionals. After three years, IMPACT will have increased service capacity and will have demonstrated a statewide service delivery model making assistive technology more available and accessible to individuals with developmental disabilities. This paper will present the model and the first year's results.

BACKGROUND

Statewide planning for delivery of assistive technology services is a relatively new phenomenon. It was not until the few years prior to passage of the Technology-Related Assistance for Individuals with Disabilities Act of 1988 (P.L. 100-407) that there was even much interest in coordinated statewide service systems. Two of the early planning efforts took place in Minnesota and New York where Governor-appointed task forces studied consumer needs and made recommendations for improved technology services (1,2). After the Tech Act was passed, other states began developing their grant applications around statewide services provision. Parette and VanBiervliet, in a report on the needs of infants and young children with disabilities in Arkansas, recommend a decentralized system of services to account for problems with transportation, information, funding and lack of hands on technology experiences by families living in rural areas (3). In South Carolina, Langton and Trachtman propose a cooperative service delivery model in which agencies operate within a regional service area to share staff and resources for more effective technology services (4). The results of the model's first year of operation suggest it is feasible if the benefits outweigh the costs of participating and if a facilitator can help maintain the necessary relationships (5). And in yet another approach, Kniskern proposes a systems integration model in which three systems levels (policy makers, service providers and consumer groups) interact both vertically and horizontally resulting in increased service capacity and a better match between consumer needs and services (6).

Certainly there is no one model for statewide delivery of assistive technology services. Most, however, would agree that state planning should be based upon needs, available resources and a set of realistic goals (7). In addition, planning must occur locally to meet citizens' needs and should take into consideration emerging critical issues such as cost/benefit, quality assurance, outcome measurement and training/certification. An interesting approach, and one which this project is based upon, is described by Schoech, Cavalier and Hoover (8). The Community Assistive Technology Services Network (CATSN) is a model for integrating technology into a multi-agency community human services delivery system. Although the development and testing of the model focused on systems change rather than on the creation of new services, the arrangement of service modules has clear implications for a statewide service delivery system. The authors present some of the barriers they faced during the project, but conclude that implementation of the model can create a coordinated network of technology services.

APPROACH

Project IMPACT (Innovative Methods for Providing ACcess to Technology) responds to an identified need in North Carolina for increased access to assistive technology devices and services for individuals with developmental disabilities and their families. As identified in the Technology-Related Needs Assessment Project - Final Report (9), consumers and families need more information on how to obtain and repair equipment, as well as appropriate training on how to use equipment. Service needs include technology-related consultation, equipment demonstration and equipment loan/rental and repair. Professionals want more preservice and inservice training on assistive technology and see a significant need for follow-along services. Consumers and professionals agree that consumers need to increase their awareness level regarding available assistive technology. Project IMPACT is a Developmental Disabilities Council-funded grant designed to address these needs through a comprehensive three-year plan of activities.

Project IMPACT has developed a model to increase service delivery capacity in North Carolina (figure 1). The principal organizations are the N.C. Assistive Technology Project (NCATP), the Clinical Center for the Study of Development and Learning (CDL) - a University Affiliated Program and the Family Support Network of N.C. (FSN). Linkages and grant management are provided by NCATP acting as a central coordinating hub. The following four goals expand the concepts shown in the figure.

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Project IMPACT
Innovative Methods for Providing ACcess to Technology

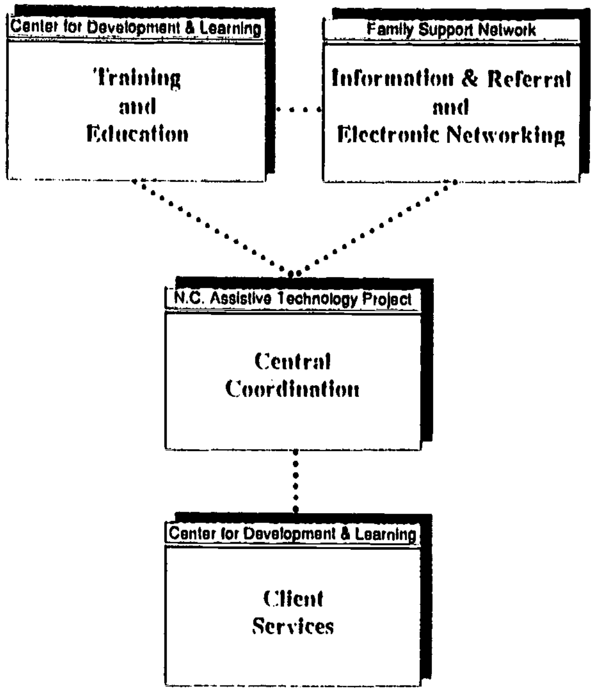

Figure 1

Goal 1. Link existing programs
A project management team consisting of the project director, coordinator and representatives from CDL and FSN meets monthly to plan and review all activities. A nine-member interagency advisory board helps guide the project. The management team works with the advisory board to develop service linkages and interagency partnerships, including developing a client tracking and evaluation system which could be used among all agencies providing assistive technology services. As the project progresses, the management team will be responsible for identifying barriers to acquiring assistive technology (such as funding, lack of trained professionals, limited access to device try-out) and will develop clear and concise plans for policy and systems changes. The management team works closely with the NCATP to help implement these changes. In addition, the project director and the management team are responsible for developing a plan for continuing project activities beyond the three-year grant.

Goal 2. Expand service delivery capacity
A multidisciplinary, state training team helps with curriculum development, training activities and regional consultation/coordination among new and existing programs. Four regional teams will be established whose role is to provide multidisciplinary assistive technology assessments/follow-along services and also to help build regional resource networks. In addition, local programs are selected in each of the four regions to serve as a model, community-based pilot projects. Pilot projects demonstrate exemplary practices of technology utilization across select ages groups. Regional teams and pilot projects work closely with local resources, such as the NCATP's technology demonstration centers, to establish a regional service delivery network. CDL provides intensive, ongoing consultation to both the regional teams and pilot projects. Pilot projects and regional teams then help with replication following their year of receiving technical assistance. A technology demonstration center in Wilmington expands service capacity in that part of the state.

Goal 3. Provide training to consumers, families and professionals
A comprehensive assistive technology training curriculum based upon existing training materials will be developed, tested, revised and completed by the project's end. This curriculum is used to help train the regional assistive technology teams and pilot projects. This training is provided by the state training team members who work closely with CDL to provide technical assistance and ongoing support. In addition, learning modules which have a consumer and family focus will be developed. Learning modules may cover such topics as technology and literacy, technology for learning disabilities and technology for the elderly. The learning modules will be disseminated to interested organizations.

Goal 4. Establish networks for information exchange
North Carolina, through FSN, currently offers a toll-free assistive technology information and referral service. Another key component for information exchange is an electronic computer bulletin board service. This bulletin board is available to consumers, families and professionals statewide through computer/modem hookup. The bulletin board offers electronic mail, discussion forums and provides current information on such topics as statewide training sessions, used equipment, legislation, and questions and answers on problems related to technology applications. In conjunction with the bulletin board, a peer support network among consumers and families helps match experienced assistive technology users (mentors) with new technology users (peers).

When fully implemented, Project IMPACT will have increased service capacity by developing and demonstrating a model, statewide assistive technology service delivery system. Model components, replicated across four regions of the state, will consist of a regional assessment team, a technology demonstration center, and a local pilot project. A statewide information network featuring toll-free and electronic access will facilitate communication into and among the service components. Training materials will help consumers and families become more knowledgeable of assistive technology, and a peer matching system will facilitate support among individuals and families who have similar needs.

RESULTS

Project IMPACT began operation in January 1993. The management team, advisory board and state training team have been integral to the project's operation. A regional team and pilot project were established in the north central region through competitive applications.

PROJECT IMPACT

The regional team is located at Murdoch Center, a residential facility for individuals with mental retardation and developmental disabilities. The Murdoch Center team will provide comprehensive, multidisciplinary team assessment and follow-along services to residents and consumers in their 16 county region. They will also provide training and community outreach. The pilot project is located at the Bowman Gray School of Medicine. Through their Physicians's Home Care Program, this model project will help older people who live at home remain independent through the use of technology. A comprehensive training curriculum responsive to the programs' needs was prepared by CDL with input from the state team, and two multi-day training workshops were conducted. CDL has continued to work extensively with Murdoch Center and Bowman Gray and is helping them develop short- and long-term program goals. A data collection system is in the final stages of development and will be implemented with the programs beginning in year two. And in Wilmington, the New Hanover Regional Medical Center has been selected for the new technology demonstration center site.

The biggest challenges faced by IMPACT have been in implementing the statewide electronic bulletin board and the peer matching program. Issues with personnel and hardware/software forced significant changes midyear to the bulletin board. However, a recent development appears very promising. The Raleigh News and Observer (the state's largest newspaper) has proposed a partnership whereby people with disabilities will be given free access to their statewide computer bulletin board service. Features will include on-line publications (such as the newspaper), discussion forums, electronic mail, Internet access, home shopping and games. A person with a disability will serve as systems operator. A written agreement is expected early in 1994. The peer matching program also has been restructured and that too is expected to begin operation this year.

DISCUSSION

Project IMPACT has been a major undertaking, both in scope and management. The proposed service delivery model has been well received and all involved parties have contributed significantly to its operation. Much of the support has been volunteer, including the state training team and the Murdoch Center and Bowman Gray programs. However, we feel that both programs have "bought-in" to the model and are committed to its success. The service network is now in place in one region of the state and the information and peer support overlays will facilitate communication into and among the components. By linking new and existing resources, we expect to build strong regional services thereby creating an even stronger statewide service delivery network. Data collection and outcome measurement will help validate the model's key attributes.

Unfortunately, a budget cut back has forced a reduced effort for year two. However, the service delivery model remains viable and local capacity building will be pursued. Project IMPACT's plans for future support consist of 1) continuation and expansion of the three sponsoring programs, 2) formation of a statewide partnership among agencies serving individuals with disabilities, 3) maintaining the regional and pilot programs initiated by Project IMPACT through fee-for-services, fund raising and in-kind support and 4) assisting regional programs to work together for more effective and efficient service delivery. Our goal is that the local and statewide resources developed by the project will lead to public and private support for these new services.

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REHABILITATION TECHNOLOGY SERVICE DELIVERY MODELS IN VOCATIONAL REHABILITATION AGENCIES: A MULTI-LEVEL APPROACH

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Abstract

Current methods for classifying rehabilitation technology service delivery models do not adequately describe these services in Vocational Rehabilitation (VR) agencies. The purpose of this paper is to present an alternative classification scheme. This scheme is being used in a national study to evaluate rehabilitation technology services in VR programs.

Background

Vocational Rehabilitation agencies, funded by the United States government, are required to provide rehabilitation technology services. A preliminary survey of VR agencies (CRTS, 1992) reported that they do provide some rehabilitation technology services to their clients. There were significant differences in the way these services were delivered and how these programs were managed. VR agencies are looking for ways to deliver these services in the most efficient and cost effective manner possible. In order to compare service delivery programs between agencies, some pattern, model, or other common basis must be identified. One method typically used in describing and analyzing service delivery programs is to categorize them according to some characteristic or set of characteristics. This paper focuses on classifying service delivery approaches used in VR agencies in order to then evaluate efficacy of the various models.

The Thirteenth Institute on Rehabilitation Issues (Corthell & Thayer, 1986) reviewed models of rehabilitation technology service delivery in a variety of settings including VR agencies. In their review, they identified models, however, no classification system was used to distinguish among the various programs nor was any external evaluation performed. While some of these models continue today and some programs have been replicated, most service delivery programs in VR agencies have not been developed following these or any other model.

Smith (1987) identified seven descriptive factors which are frequently used to classify and describe rehabilitation technology service delivery models: (1) purpose and mission; (2) functional area; (3) geographical catchment area; (4) population; (5) internal operations; (6) location; and (7) administrative home base. A closer examination of these descriptive factors reveals that, while they may be useful in a general sense, many are not useful in discriminating among rehabilitation technology service programs in VR agencies. The descriptive factor "administrative home base" refers to the type of organizational setting in which the program operates. Since all of the programs to be studied are part of VR agencies, this factor would not discriminate among programs. Several other descriptive factors - purpose and mission, population, and functional areas - would not adequately discriminate VR rehabilitation technology service delivery programs because, as a part of the VR program, these programs must follow federal requirements which mandate that rehabilitation technology services be available to all eligible clients. They could differ in <u>how</u> they provide these services but not <u>whether</u>, or to whom, they provide them. Factors which are useful in discriminating among VR programs include: geographical catchment area, internal operations, and location.

"Geographical catchment area" is the geographical territory which the program serves, typically state, county, or community. This is viewed as one of the most common ways to categorize service delivery programs (Smith, 1987). Although all VR agencies provide statewide services, the way in which they organize the delivery of rehabilitation technology services varies across agencies. For example, some agencies divide the state into multi-county regions and assign technology staff to deliver services in a specified region. Other agencies do not divide the state. Instead, rehabilitation technology services are provided from an office or several offices each of which serves the entire state.

"Internal operations" addresses the management, staffing pattern, structure, or other aspect of program operations. One aspect of staffing pattern relates to type of staff. A VR program might follow the single expert model, the interdisciplinary team model, or some model in between. Staffing can also vary from "employee-based" with full time technology staff hired by the agency to "outside provider-based" with contractual-based service providers.

"Location" refers to the position, station, or situation in which services are provided. Location discriminates among VR rehabilitation programs. Langton, Gaster, and Trachtman (1991) identified two locations: stationary and mobile. A mobile service delivery unit operates out of a vehicle that travels to see clients in their homes, jobs, or at a convenient public facility such as a regional VR office. The primary purpose of the vehicle is to provide a place to conduct assessment, fabrication, and/or other services. The stationary service delivery approach operates out of a facility. Clients come to the facility to receive rehabilitation technology services. The service provider may occasionally go out to other sites to provide assessment or delivery of a device, etc., but the base of services is non-mobile. Using this concept of stationary, a more accurate term might be facility-based. This may seem confusing since most people who provide rehabilitation technology services go to the consumer's home, work place, the local VR office, or some other facility. The difference is that the mobile unit carries with them the capability to fabricate, repair, or provide related services on site without going back to their home office.

Statement of the Problem

- A classification scheme is needed which discriminates among VR systems in order to compare efficacy of the various programs that exist.
- Current classifications do not, in their entirety, discriminate among the various VR rehabilitation technology service delivery programs.
- Three factors from previous classification schemes do appear to discriminate.
- Since all of these factors discriminate among VR rehabilitation technology service delivery programs, using all of these factors will provide a more powerful classification of programs.

Approach

Eight service delivery models are proposed to classify VR rehabilitation technology service delivery programs using the three factors identified as discriminators. In order to classify programs into one of the above models, several questions were developed for a comprehensive survey sent to all VR agencies. Questions included: how the delivery of rehabilitation technology services are structured, what percentage of rehabilitation technology services (apart from product sales) provided to VR clients are delivered by VR employees and what percentage are provided by outside service providers, and what percentage of rehabilitation technology services offered by VR are provided from a vehicle and what percentage from a facility.

Results and Discussion

Partially or fully completed surveys were returned from 62 VR agencies for a return rate of 77%. Of these, 58 completed Section 3 of the survey which dealt with rehabilitation technology services. Where the program does not fall at one end of the continuum or the other (e.g., they have employees and they contract with outside service providers), the predominant characteristic is used to classify the program. For example, if 75% of their services are provided by employees, they are classified as internal.

The models reported by states are:

regional/internal/facility-based [N=9]
central/internal/facility-based [N=13]
regional/external/facility-based [N=19]
central/external/facility-based [N=8]
regional/internal/vehicle-based [N=1]
central/internal/vehicle-based [N=0]
regional/external/vehicle-based [N=1]
central/external/vehicle-based [N=2]

This system appear to discriminate among rehabilitation technology service delivery programs in VR agencies. As with any classification system which is imposed after the program was developed, it doesn't totally fit. One difficulty with the descriptive factors proposed is that they exist on a continuum. For example, the internal operations can exist on a range from 100% employees to 100% outside service providers. The model focuses on the ends of the continuum for each factor. In most cases, the program existed closer to one end of the continuum. For those programs that existed closer to the middle, classification was more difficult and less meaningful. Some programs even had both regional and centralized services operating within their agency. This usually occurred with some specialized program which provided services across the state while routine rehabilitation technology services were provided by region. In these cases, the program was classified as regional since most of their services were provided using the regional model. Classification according to internal operations appears to be closer to the middle of the continuum rather than at one end or the other. Five programs could not be identified as either internal or external because they have 50% employees and 50% outside service providers. Of the five programs which could not be classified according to internal/external, only one was vehicle-based. Very few agencies (5) primarily provide these services using the vehicle-based model. Current work uses this classification system to analyze the efficacy of the various rehabilitation technology services delivered in VR. Detailed data on cost, activities, and time use are underway in pursuit of this goal.

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TETRA SOCIETY OF NORTH AMERICA: THE FIRST THREE YEARS

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TETRA SOCIETY

ABSTRACT

The range of physical disabilities is enormous, and the needs of people with the same disability varies greatly with each individual; thus it is impossible for the market to provide all the products and assistive devices people with disabilities require. Tetra Society of North America has united technical volunteers and disabled people to provide hundreds of low-cost assistive devices from 1990-1993.

BACKGROUND

Organizations have been formed to mobilize skilled volunteer labour to provide the technical assistance people with disabilities require. In Australia a highly successful program known as Technical Aid to the Disabled (TAD) matches professional engineers on a one-to-one basis with clients with disabilities. A similar program called REMAP operates in Britain.

In Vancouver, Canada, Tetra has developed the Technical Assistance Program (TAP) modeled after TAD and REMAP. The organization was founded and is directed by a quadriplegic, Sam Sullivan. Tetra has completed over 500 projects since its inception in 1989. The group has over 250 active volunteers and 15 chapters operating across Canada. Tetra is presently undertaking expansion by development of additional chapters across North America.

OBJECTIVE

Tetra has two objectives:

* to assist people with severe disabilities to become as independent as possible so they can fully participate in their own communities

* to promote awareness of the abilities, skills and talents of people with disabilities and to encourage their integration into the workplace

DISCUSSION

An organization linking volunteers with disabled individuals to provide low-cost assistive solutions provides several community benefits:

* customization. Tetra is able to offer the disabled client complete customization of the device through direct linkage with the technical volunteer

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* cost effectiveness. The devices are provided in a manner that is far less expensive than similar solutions produced through institutional channels, because of the volunteer component of the production process

* promotion of inclusion. The devices produced allow disabled people to enter into daily activities previously barred to them, promoting inclusion and independence

* promotion of sensitivity and awareness. Volunteers become sensitized to the needs of the physically disabled and the potential means by which these needs can be met. Medical professionals working with Tetra learn from the volunteers how simple and inexpensive many technical solutions are:

ACKNOWLEDGEMENT

Tetra receives funding from a variety of community, corporate and governmental groups.

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PROJECT IMPACT: Innovative Methods for Providing Access to Technology

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ABSTRACT

Project IMPACT represents a partnership among three organizations to improve and expand access to assistive technology services for North Carolinians with developmental disabilties. A large component of the project is devoted to the selection and training of regional assistive technology teams to expand service delivery capacity. Additionally, pilot projects which showcase the unique application of assistive technology are selected and included in the resources for each region. The regional assistive technology teams and pilot projects are provided with training on a variety of topics to enable them to address evaluation, follow-up and specific project related training needs. This paper will present the training model used and actvities from the first year.

BACKGROUND

As the theoretical and research base for assistive technology service continues to expand, so does the need for effective service delivery and training models. A variety of service/training delivery models have been proposed to best provide assistive technology services (Trachtman & Sauer, 1994; Beukelman D., & Mirenda P, 1992; Schoech, D., Cavalier, A., and Hoover, B., 1993; Blackstone, S., 1989; Blackstone, S. & Cassett-James, E. 1988; Matas, J., Mathy-Laikko, P., Beukelman, D., and Legresely, K. 1985; Cohen, C. & Frumkin, J., 1988; Cohen, C. 1986;Vanderhaiden, G. & Lloyd, L. 1987; Shane H., & Yoder, D. 1981). Often, consumers and families travel great distances to receive services. Once the service is provided, follow-up and long term management are difficult for all concerned. Project IMPACT represents a compilation of various attributes of these described service delivery models as a vehicle for meeting service/training needs in North Carolina. The mechanism for accomplishing these tasks was created by utilizing and expanding the capabilities of existing programs in the state (Center for Development and Learning-University of North Carolina, North Carolina Assistive Technology Project, and Family Support Network- University of North Carolina). The project activities were selected based on needs surveys conducted state-wide as well as those described by parents, consumers and professionals. It is the training component of the project which this discussion will describe.

A variety of service delivery and training issues have been described by the above authors.
These include variables related to specific disciplines as well as a host of broader issues such as administrative policy, client programming, professional training, referral process, resource availability, staff roles, interagency communication and cooperation, information and program awareness, technology availability, funding programs and equipment. As described by Church and Glennen (1992), " a newly developing assistive technology program should seek to recognize any constraining factors and to develop the best possible program within those limitations. Rather than trying to develop an all encompassing assistive technology program that tries to do all things for all persons, the team should limit services to those areas which can be performed well." It is this approach which was adopted to address the training initiatives of Project IMPACT.

APPROACH

Project IMPACT divides the state of North Carolina into four regions. Each of the these regions is supported by a regional resource center where parents, consumers and professionals can come for additional information, hands-on experience with devices (lo-tech and high tech). Each offers a varying array of educational programs from funding to specific device training and use. Evaluation and service delivery is not offered through the centers. In an effort to provide a service delivery system and link

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parents and consumers state-wide, the project proposed a service delivery system which would offer the following components to each region of the state:

a) interdisciplinary service delivery team for evaluation, intervention and follow-up; b) pilot project to showcase special applications of assistive technology and augmentative communication strategies; c) linkage of service delivery teams and pilot projects to regional center activities to provide resource information and hands-on for parents, consumers and professionals; d) electronic bulletin board to link parents and consumers directly.

Training Model

Each of these components has the potential of enhancing and expanding service delivery capacity statewide. However, as recognized by Cohen (1986), "technology teams require highly trained professionals who specialize in the field." Additionally, as addressed by Church and Glennen (1992), "a multidisciplinary model of providing assistive technology services requires coordination across disciplines. A team leader is needed to coordinate services and resolve team differences. The team leader needs to be familiar with technology issues across all team areas but does not need to be an expert in each discipline." In order to expand services it was necessary to: 1) identify existing resources within each region of the state, 2) identify the assistive technology and pilot project teams and their individual and organizational capabilities, and 3) provide training and follow-up support to the teams identified within each region. Training activities were provided utilizing expertise from professionals, consumers and family members statewide to regional and local programs.

A multidisciplinary state training team was established to recognize existing assistive technology expertise in each region and to furthermore provide representation from each region of the the state. Their involvement includes recommendations for specific activities within each of the four regions of the state and curriculum and material development.

Regional assessment teams and pilot projects are selected in each region on a competitive basis. To date, two regional assessment teams have been selected and one pilot project. The pilot project is a home health care program serving persons who are elderly to enable them to stay in their homes rather than moving to an institutionalized setting. These groups will maintain an ongoing relationship with Project IMPACT. The initial training phase is approximately nine months long followed by follow-up and consultation to the teams as needed. This is determined largely by team development and differs from group to group. Factors which affect this include 1) familiarity with assistive technology at the onset of project activities 2) organizational capability of the team 3) organizational capability of the agency 4) requests by the team for assistance.

Training Activities

Following selection, each group was given a questionnaire which closely mirrored the proposed training curriculum. Team members were asked to identify their level of expertise across each of the curriculum topics. These questionnaires were used by the training staff to customize training to the identified strengths and weaknesses of the team as a whole and individuals.

Training included: 1) two, three-day training workshops at the beginning and midway through the training period, 2) ongoing on-site consultation weekly or bi-weekly, 3) ongoing consultation via electronic link directly to training staff at the Center for Development and Learning 4) observation of team evaluations and service at the Center for Development and Learning 5) working closely with regional assistive technology resource centers to network goals of selected programs with the center.

The training curriculum includes a compilation of articles, resource lists and excerpts from available assistive technology curriculums from projects and agencies nationwide. The curriculum is presented to training participants in a notebook. Additional resources are added as training progresses. Members of the state team provide training utilizing information from the curriculum and the questionnaires. In some instances, training is provided by outside consultants when the state training team cannot provide the necessary expertise on a specified topic (i.e. dual sensory impairment).

RESULTS

To date, this training model has been an effective vehicle for training. Critical to its evolution has been the recommendations and suggestions provided by state team members as well as evaluation of project activities by selected regional teams and the pilot project. In this way, training activities have been modified for more efficient and appropriate use of training time. Utilizing existing assistive technology expertise within the state, strengthened the networks within each region as well as established/identified resources for the regional teams within their local areas. The inclusion of the regional teams in the training activities for the subsequent regions has been helpful to those most recently selected.

The initial selection process used for the regional team and pilot project is essential. This has enabled Project IMPACT to select teams or programs which have the necessary administrative support and personnel to establish and maintain service at project's end. In each case, the regional teams and pilot project have selected team leaders to coordinate their efforts and provide guidance to the team. This has been encouraged by project training staff but has been a natural evolution of team capacity building.

The training curriculum will be revised and used throughout the remainder of the project. It has clearly demonstrated the need for an assistive technology curriculum which effectively addresses the training needs of a multidisciplinary team rather than individual disciplines. It was a challenge to use available materials to construct this type of curriculum.

DISCUSSION

As suggested by Church and Glennen (1992) the most essential ingredient in Project IMPACT training has been the identification of the strengths and unique characteristics of each team rather than trying "to do all things for all persons, the team should limit services to those areas which can be performed well.". In this way, they have become aware of their own capacity and the unique capability of each regional team to their own community and to other regional teams.

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REHABILITATION ENGINEERS IN VOCATIONAL REHABILITATION AGENCIES: A PROFILE

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Abstract

This paper describes the role of rehabilitation engineers in vocational rehabilitation agency settings. Their educational backgrounds, nature of duties and responsibilities, and extent to which they provide services in specialty areas are profiled.

Background

Although there have been studies on job tasks and functions of rehabilitation service providers (Beardsley and Rubin, 1988), only a few have been conducted on rehabilitation technology professionals. Rehabilitation engineers differ from other engineers as they are required to incorporate their engineering skills along with their expertise in evaluating clients with disabilities, identifying needs and recommending solutions (Ellingson, 1983). However, rehabilitation engineers lack an identity that distinguishes them from others. The role confusion of rehabilitation engineers is not new (Trachtman, 1991). The lack of a common definition for rehabilitation engineer's qualifications and the ambiguity of their roles are two primary factors contributing to the confusion (RESNA, Jan-Feb, 1992). Because of this, people may tend to call themselves rehabilitation engineers based on their job duties rather than their educational background. It is not the intent of this paper to define a rehabilitation engineer or address certification and accreditation issues. Rather, the purpose of this paper is to provide a profile of rehabilitation engineers and rehabilitation technology professionals in VR agencies, a primary provider of rehabilitation technology services. This paper attempts to investigate the nature of the job duties, work experience, responsibilities and educational background of rehabilitation technology providers in VR agencies.

Research Questions

1. What is the educational background and experience of the rehabilitation engineers in VR agencies?
2. What percentage of time is devoted to various activities (e.g., service delivery, management/administrative, etc.)?
3. How often specific types of services (e.g., assessment, design, training, etc.) are provided?

Method

A comprehensive survey was sent to all VR agencies funded by the US government. The survey consisted of three parts: (1) an overview of the agency, (2) assessment/evaluation of VR clients and, (3) rehabilitation technology services respectively. An additional questionnaire accompanied the third part of the survey with questions addressed specifically to rehabilitation engineers employed by or contracting with VR agencies. For the purpose of this survey, a rehabilitation engineer is defined as anyone who identifies him/herself as a rehabilitation engineer. Technology staff who considered themselves rehabilitation engineers were asked to complete the form, regardless of job title. Full-time/part-time VR employees as well as outside providers returned the forms along with other parts of the comprehensive survey. For the purposes of this study, outside providers are considered to be those who provide rehabilitation technology services to a VR agency on a contractual basis.

Results and Discussion

One hundred sixteen rehabilitation engineer questionnaires were returned. The questionnaire asked respondents to report their job title. Since there were a large variety of job titles reported, they were coded into six categories. These include:

- Rehabilitation Engineers (N=39)
- Rehabilitation Technology Specialists (N=36)
- Other Engineers (N=7)
- Administrator/Engineer (N=9)
- Administrator/Other (N=11)
- Other (N=13)

Rehabilitation Engineers are those with a job title which includes the term rehabilitation engineer. Rehabilitation Technology Specialists are those with a job title related to some type of technology but not

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specifically mentioning engineering (e.g., rehabilitation technician, assistive technology specialist, etc.). Other Engineers are those with a reference to engineer in their job title but with no specific reference to rehabilitation engineer (e.g., facilities engineer). Two categories of administrators were identified: administrator/engineers and administrator/other. Administrator/Engineers are those who have both an administrative and an engineering reference in their job titles (lead engineer, senior clinical rehabilitation engineer, etc.) Administrator/Other are those with an administrative reference but no engineering reference in their job titles (e.g., chief, Rehabilitation Technology).
Others are those who could not be placed in one of the other categories (e.g., vocational evaluator, career development specialist, etc.).

Educational Background

Table 1 shows the highest degree earned, number of engineering degrees, and professional engineering certification held by the various rehabilitation technology providers.

Table 1: Highest Degree Earned by Rehabilitation Technology Providers by Job Title

Job Titles for Rehabilitation Technology Providers

Educational Background	Rehabilitation Engineers	Rehab Tech Specialist	Admin/ Rehab Engineer	Other Engineer	Admin/Other	Other
High School	2	3	0	0	1	0
Associate Degree	0	4	0	0	0	1
Bachelors Degree	18	17	5	4	4	7
Masters Degree	16	11	2	2	5	4
Doctoral Degree	3	0	2	1	0	1
Engineering Degree*	34	7	10	7	5	7
Professional Engineers	3	1	3	2	0	1

*Either Bachelors, Masters, Ph.D. separately or in combination

From the table it can be seen that the 39 rehabilitation engineers hold a cumulative total of 34 degrees in engineering. On the other hand the 36 technology specialists hold a total of 7 degrees in engineering. For all providers 10 are professional engineers.

Activity Areas

Table 2 presents a breakdown of time spent by rehabilitation technology providers in various activity areas.

Table 2: Average Percentage of Time Spent in Activitiy Areas for Rehabilitation Technology Providers by Job Titles

Job Titles for Rehabilitation Technology Providers

Activity Areas	Rehabilitation Engineers	Rehab Tech Specialist	Admin/Engineer	Other Engineers	Admin/Other	Other	TOTAL
Management/ Admin Activities	10.33	9.64	21.89	15.71	42.36	17.3	15.2
Service Delivery	64.33	57.89	33.56	45.0	38.18	49.08	54.5
Community Service	6.46	11.89	6.44	14.29	5.45	17.77	9.82
Training	9.28	8.56	10.22	9.43	9.09	13.15	9.56
Research	4.92	6.25	17.78	4.14	4.0	6.38	6.37
Other	2.61	4.81	10.11	3.57	0.91	3.84	3.93

A number of analyses were performed on the data in Table 2. For management activities, those in the Administrator/Other category spent significantly more time (M = 42.4) than did Rehabilitation Engineers (M = 10.3), than Other Engineers (M = 15.7), and than those in the Other category (M = 17.3), $F(5,109) = 7.03$, $p < .001$. Rehabilitation engineers spent significantly more time in service delivery activities (M = 33.5) than Administrators/Engineers (M = 64.33), $F(5,109) = 3.45$, $p < .01$. Finally, Administrator/Engineer spent significantly more time in research activities (M = 17.78) than did Administrator/Other (M = 4.0), than Rehabilitation engineers (M = 4.9), and than Rehabilitation Technology Specialists (M = 6.25), $F(5,109) = 2.94$, $p < .05$. No other analyses were significant.

Rehabilitation Technology Services Provided

Table 3 displays a rank ordering of how often the various rehabilitation technology services are provided by those whose primary work activity is service delivery. Types of services provided were rated on a 5 point scale according to the frequency of the services provided. One indicates the service was never provided and five indicates the service was almost always provided.

Table 3: Frequency of Types of Services Provided

Types of Service	Mean Frequency Rating
Evaluation/Assessment	4.2
Recommendations/Prescriptions	4.1
Equipment Procurement	3.8
Fitting/Adjustment	3.3
Custom Design	2.9
Fabrication/Adaptation	2.7
Device Training of Consumers/Caregivers	2.6
Maintenance/Repair	2.6
Follow-Up	2.6
Equipment Loan	2.5
Product Demonstration	2.5
Funding Assistance	2.4
Education and Training	2.0
Consultation/Technical Assistance	1.7
Other	0.13

Work Experience

Figure 1 depicts the number of years of work experience as a rehabilitation engineer reported by those whose job title was Rehabilitation Engineer.

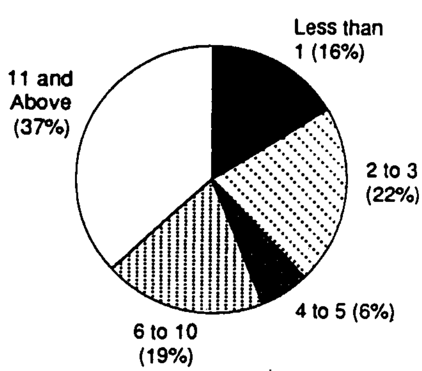

Figure 1. Rehabilitation Engineer's Years of Experience

Current work focuses on the relationship between educational backgrounds and services provided. For example, does a rehabilitation engineer with a computer science degree tend to do more computer access work versus one with a mechanical engineering degree who tends to work with wheelchairs? In addition, detailed data on academic curricula are being collected in order to examine whether training programs meet the needs of rehabilitation technology service providers.

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ASSISTIVE TECHNOLOGY USAGE OUTCOME: A PRELIMINARY REPORT

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ABSTRACT

The provision of assistive technology appears to enhance the functional abilities as well as quality of life of the disabled individual. Service providers however must begin actively addressing issues of the appropriateness and the necessity of assistive technology. This interactive paper will report on preliminary data from a long term outcome study designed to address the issues of usage and the appropriateness of assistive technology as well as to identify the underlying and contributing elements associated with non-usage.

BACKGROUND

Advances in the assistive technology arena have moved forward a such a rapid pace that they have stifled many of the necessary changes for adequate service provision, public policy revisions, and the reallocation of scare resources. At times it appears that we are no longer capable of adequately keeping up. The increasing demands for accountability at all levels has become apparent. As a result, successful outcomes management has become the vogue topic of the 90's and will serve as the professions survival in the new century.

Within assistive technology, very little in the way of outcome studies has been done. On the surface, the results of those studies that have been conducted do not necessarily reflect positive outcomes or successful assistive technology utilization.

OBJECTIVE

In order to adequately examine outcomes, one needs to look beyond traditional surface outcome data elements of success/failure or usage/non-usage of the product. Instead, there must be an examination of the underlying elements that potentially contribute to the ultimate outcomes.

APPROACH

This project developed a measurement protocol that enabled the capture of surface as well as underlying and potentially contributing outcome elements. Data on these elements has been collected at four time intervals (following delivery/training and at 6 months, 1 year and 2 years post delivery).

DISCUSSION

To date, the assistive technology usage outcomes database includes 86 subjects who are at various stages in the data collection process. The current database encompasses a sex distribution of 57% male and 43% female. The age of the subjects at the point of initial data input ranges from 2 years 11 months to 21 years 8 months with a mean age of 13 years 7 months. The breakdown of types of equipment includes 59% augmentative and alternative communication systems, 27% computer systems, 9% environmental control units, and 5% other types of assistive technology. Although data collection on this project is ongoing, preliminary outcome data will be presented during this session.

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MODIFYING COMMERCIALLY-AVAILABLE WALKERS TO MEET INDIVIDUAL NEEDS

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ABSTRACT:

This paper describes two clinical cases in which commercially-available walkers were modified to meet two individuals' needs. The walkers were adapted to provide the support necessary to improve their posture and their ambulation. While the modifications were specific to these individuals' needs, they could easily be applied to others with similar needs.

BACKGROUND:

Many individuals possess mobility impairments that significantly affect their daily lives. According to the National Center for Health Statistics, over 3,500,000 persons in the United States are either unable to walk or cannot walk without some form of assistance.[1] Of these people, approximately 700,000 rely on walkers for mobility. These individuals are of all ages and possess a variety of disabilities.

Walkers are available commercially in a variety of sizes, styles, and configurations, thereby facilitating a satisfactory fit to most users. Unfortunately, commercial walkers do not meet all individuals' needs. For some individuals, a commercial walker may require custom modification. This was the case for two clients recently seen for rehabilitation engineering services.

The first case involves a three year old girl with arthrogryposis. Arthrogryposis Multiplex Congenita is a non progressive, congenital syndrome characterized by multiple contractures, rigid joints and significant limitation of movement.[2] Specifically, the girl has no functional use of her upper extremities, but does possess passive range of motion at the shoulder. She has good hip flexion and extension, but limited knee mobility, and her ankle and foot motion is normal.

Due to her disability, this girl is unable to walk without assistance. Prior to engineering intervention, she could walk with another person lifting her under the axillae. With this support, the girl could move her legs by flexing her hips to propel herself forward with a gait similar to a soldier's march. Over time, she would become fatigued, and would flex at the waist, resulting in a poor walking alignment.

The second case involves a five year old boy with mixed cerebral palsy that includes an athetoid component. He has fluctuating muscle tone, resulting in a lack of proximal stability and an inability to sustain an upright posture. He used a Rifton adjustable walker, which includes a padded abdominal ring and a vinyl seat sling. The boy also possesses a Guardian Strider walker which in its commercial form was unusable. While in the Rifton walker, he bore minimal weight through his feet, resulting in suspension at the perineum by the seat sling. Upon removal of the sling, he would hang by his axillae on the abdominal ring. When the boy stood with his knees mechanically locked, he was able to briefly maintain proper alignment with minimal trunk support. However, knee and trunk control was inconsistent.

OBJECTIVE:

The objective in each case was to provide the least restrictive and most mobile walker for the child, while simultaneously improving his or her walking posture. For the girl, the goal was to provide a walker that did not require upper extremity function for postural support. The girl's posture needed to be supported in a manner that was comfortable and not potentially damaging (i.e., axillary lift and associated crutch paralysis). For the boy, the goal was to incorporate a different method of providing vertical support to eliminate the seat sling currently in use on the Rifton walker. The ultimate goal for the boy, as written in his IEP, was to discontinue the use of the Rifton walker in favor of the less restrictive and more practical Strider walker.

METHOD:

For the girl, it was necessary to provide an assistive device which would replace the personal attendant

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used for ambulation. A commercially-available Guardian Tyke walker was chosen for its appropriate size. The walker needed to be modified to support the girl in an upright posture. The three areas needing support are the upper body, the arms, and the buttock. To support the upper body, an Otto Bock head rest was mounted to the front of the walker and used as a chest support. The arms were supported by two 4" X 6" padded wooden boards placed on each side of the chest support, and attached with Miller's adjustable hardware. Finally, support was needed at the buttock to keep it from drifting posteriorly. This was accomplished by adding a flat, padded gate. The gate swings open to allow easy entrance into the walker and latches shut. When the girl is positioned between the chest support and the padded gate, her body is supported in an erect walking posture.

When fully supported in the walker, the child needs to generate the forces required to propel the walker. To facilitate this, the small plastic wheels on the front and back legs of the walker were removed. The front wheels were replaced with larger rubber wheels with less rolling resistance, while the back wheels were replaced with rubber stops. Pushing the walker would have been made easier with wheels on the back legs, but the posterior force of the buttock caused the walker to roll backwards when these wheels were in place. To add incentive for pushing, pegs were added to the arm pads and positioned slightly in front of the hands.

For the boy, it was necessary to provide appropriate support that would redistribute the pressure exerted by the seat sling and abdominal ring of the Rifton walker. To accomplish this, a parachute body harness was used as a model. In a parachute harness, the body weight is supported by padded straps that pass from the waist to behind and below the acetabula, then up between the legs to an attachment point on the waist. Other straps extend from the waist to pass over the shoulders, and then attach to the parachute itself. When in place, the body weight is borne by the acetabula, with the resulting upward lift transferred through the harness to the parachute. The parachute harness model was redesigned for use with a walker by redirecting the shoulder straps to extend from the waist to the horizontal tubing of the walker, which provided an upward lift and partial weight-bearing relief. Additional trunk support was provided by anterior and posterior straps across the waist.

To fabricate this harness, the H-style posture belt by Adaptive Engineering Labs, having a strap configuration similar to the parachute body harness, was modified. The modifications included the addition of four straps and six buckles, reorientation of straps, and the adjustment of strap length. The padded shoulder straps of the chest harness were used as the primary weight-bearing straps that pass below the acetabula. The harness was attached to the walker and fitted to the client, resulting in a superior walker support.

RESULTS:

In the case of the girl, after the walker was provided, she needed to be taught to move her legs and to push the device forward. With practice, this child was able to walk across a room. Problems did arise with the device after use, though. Due to her limited strength, the girl had difficulty moving the walker on plush carpet. Although the new wheels helped, the walker was most successful when used in her school, at the mall, and on other flat, smooth terrain.

After a year of using the walker, this child was able to walk around her school, as shown in Figure 1. She can now maneuver it around turns, which takes extra effort because she is unable to lift the walker. As her walking and posture improved, the back gate of the walker was removed. Once she was successful at walking without the gate, the girl's therapists wanted her to be able to walk backwards. A vinyl band was added behind the buttock that could be pushed when necessary to scoot the walker backwards. The only other modifications to the walker were the removal of the hand pegs and the extension of the legs to accommodate the child's growth.

For the boy, the harness promotes upright posture and redistributes the pressure to the acetabula. The harness interfaces with both of his walkers. When used in the Rifton walker, it replaces the seat sling yielding a much more comfortable support. When attached to the Strider walker, the harness provides the vertical support necessary for its use, as shown in Figure 2. With both walkers, the harness allows complete freedom of movement during ambulation and significantly improves the boy's posture and independent mobility.

Figure 1 - Girl Using Modified Walker

Figure 2 - Boy Using Modified Walker

DISCUSSION:

In these two cases, commercially-available walkers were modified to meet each child's individual needs. These walkers were successfully altered by applying forces to each child's body to obtain erect posture and overcome relative weaknesses. Currently, each child is able to ambulate on his or her own in a successful fashion. For the 3 year old girl, her walker provides for the first time the ability to walk on her own in a safe and comfortable posture. For the 5 year old boy, his harness allows him to attain the goal of his IEP of walking with his Strider walker.

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INTEGRATION OF TECHNOLOGY INTO A NEW OCCUPATIONAL THERAPY CURRICULUM

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ABSTRACT

While many existing occupational therapy (OT) schools have retrofitted their curricula with additional coursework in technology, other programs in OT have redesigned their curricula with a core of technology related content. This paper describes a developing entry-level OT program in which technology was designed as an integral part of the curriculum. In this new curriculum, students spend a total of 365 out of 855 possible classroom hours in technology related content and have an additional 150 hours of outside assignments related to technology.

BACKGROUND

Although OT practitioners have been involved in aspects of technology since the inception of the profession, entry-level OT curricula have been slow to add instructional units or additional courses in addressing the technological needs of practicing OT practitioners. In a recent survey, 69% of the responding occupational therapists had recommended technology during their previous two years of practice (1). The OT schools, however, have not kept current with the needs of practicing therapists. A survey of entry-level OT curricula found that half of the responding schools provide less than 20 hours of technology training while 25% of entry level curricula provide between 20 and 50 hours, and 25% of the schools have more than 50 hours devoted to technology training (2).

Entry-level OT curricula have addressed the addition of technology in various ways. In 1983 Washington University was one of the first programs to add a required OT course in technology. The University of Wisconsin-Madison created two interdisciplinary technology specialization programs, TechSpec in 1988 and InterACT in 1992 (3), while the University of Washington developed a technology training core in the undergraduate curriculum with a core course and technology units in other courses (4).

In 1993 the Standing Committee of the American Occupational Therapy Association (AOTA) Technology Special Interest Section (SIS) published technology competencies, training guidelines, and areas of technology content (5). This group developed technology competencies for occupational therapists at the Foundation Level, Technology Specialist Level 1, and Technology Specialist Level 2. The Technology SIS recommends that OT curricula integrate those minimum competencies of the Foundation Level.

OBJECTIVE

To add content in technology, existing OT schools must either find room in courses already overflowing with information or decide whether to add a technology class as a required or elective course. Either decision results in retrofitting the OT curriculum with technology content. In a developing OT program, however, the objective is to design technology, from the very beginning, as an integral part of the new curriculum.

APPROACH

Using a systems approach for integration across courses, the curriculum designer designated technology as one of eight strands (health promotion and disease prevention, ethics, professional communication, research, cultural diversity, technology, collaboration with certified occupational therapy assistants, and professional conduct) to thread throughout the "tapestry" of the OT curriculum.

To comprehend the inclusion of technology as one of eight interwoven strands, first an overview of the curriculum is needed. The four year OT baccalaureate program is divided into prerequisite and professional components. After completing 59 hours of prerequisite courses, students apply for admission into the professional component which consists of 65 credit hours including a minimum of 1060 hours of clinical experience.

As a framework for the design of the professional component, the curriculum designer used *Uniform Terminology for Occupational Therapy* (6) which divides human function into three occupational performance (OP) features: components, areas, and contexts. OP areas (OPA) include activities of daily living (ADL), work and productive activities, and play/leisure activities; OP components (OPC) consist of sensorimotor, cognitive, and psychosocial skills; and OP contexts are comprised of temporal and environmental aspects. Two of the five core courses are named after the OPAs and three after the OPCs. Lifespan and OP contexts are dimensions across the five core courses, since the performance of persons needing OT services varies with age and environment. The curriculum uses a multiframe theoretical approach with five frame of reference categories: acquisitional, biomechanical, developmental, occupational behavior, and rehabilitation.

Students accepted into the professional component must first demonstrate competency in computer hardware and software applications including word-processing, database, and spreadsheet. In integrating the technology strand into the professional component, the curriculum designer utilized Smith's (7) delineation for the OT profession of two technology categories: support of therapy and direct therapeutic intervention. OT personnel use therapy support technologies for indirect patient care functions such as administrative, research, educational, and documentation tasks. Smith (7) subdivides direct therapeutic technologies into rehabilitative and educational technologies (used to remediate function) and assistive and adaptive technologies (used to supplement or substitute for lack of intrinsic function).

For each of the 17 courses (57 credit hours) which comprise the didactic portion of curriculum, Table 1 shows both the technology codes (direct [D] and support [S]) and the hours spent in lecture and lab formats as well as time spent completing outside assignments related to technology. Students spent a total of 365 classroom hours (lecture and lab formats combined) out of 855 possible hours (57 credit hours multiplied by the standard 15 clock hours per credit hour). Forty-three percent of class time with an extra 150 hours of outside assignments is related to technology. In addition to the didactic portion of the curriculum, students spend a minimum of 1060 hours in clinical experiences. Students are expected to integrate their technology related information into their clinicals.

After receiving the recent publication (5) that included the Technology Competencies for Occupational Therapists, the curriculum designer conducted a course by course audit. Table 2 displays each technology competency for the Foundation Level and the corresponding OT course numbers in which the competency is included. In this developing OT program, each Foundation Level technology competency is addressed in two or more courses.

IMPLICATIONS

According to Hammel and Smith (5), the adoption and implementation of technology competencies into preservice educational program is the first step in the process of establishing OT within the assistive technology service provision arena. With the thread of technology interwoven throughout the preservice educational program, this developing entry-level OT program should be one of the first curricula in the country to fulfil the minimum competencies in technology. Students graduating from this program will have the means to operate at the Foundation Level in the assistive technology service provision arena and the methods to seek additional information to move to Technology Specialist Level I. In a recent survey (2), technology content in OT schools ranged from 0 to 73 hours in lecture format and from 0 to 113 hours in lab format. With 120 hours of lecture, 245 hours of lab, and 150 hours of out-side assignments for a total of 515 hours of tech-nology related information, this developing OT pro-gram exceeds maximum number of technology training hours indicated by the reporting OT curricula.

DISCUSSION

While many OT schools have retrofitted their curricula with additional required or elective coursework in technology, other programs in OT have redesigned their curricula around a core of technology related content. Curriculum redesign and coursework retrofit are two methods that have been used successfully in existing entry-level OT programs. In their 1993-94 annual reports, all existing OT programs must show compliance with the most recent revision of the accreditation essentials (8) which includes technology (Essential II.B.4.g. Use of technology in service provision and analysis of data when indicated).

The developing entry-level OT program, on the other hand, has the luxury of creating all coursework from the very inception and can easily build the curriculum around technology. To improve technology expertise of entry-level occupational therapists, the curriculum designer challenges other developing entry-level occupational therapy programs to plan technology as an integral part of their curricula.

	Course Name (Credits)	C	L1	L2	A
151	Orientation to OT (1)	S	2	0	5
315	Applied Movement Analysis (3)	D	10	20	10
310	Applied Path I (3)	D	5	10	10
312	Applied Path II (5)	D	5	10	5
320	Pro Communications (3)	S	5	10	5
330	Media and Modalities I (3)	S&D	5	15	10
331	Media and Modalities II (3)	S&D	10	35	25
340	OPC I: Psychosocial Skills (5)	S&D	3	5	5
341	OPC II: Sensorimotor Skills (6)	S&D	15	20	15
342	OPC III: Cognitive Skills (3)	S&D	6	10	5
440	OPA I: ADL and Leisure (4)	S&D	6	20	10
441	OPA II: Work (4)	S&D	15	30	10
380	Pro Assessment (3)	S	10	25	10
470	Pro Issues I (3)	S	5	5	5
480	Pro Issues II (2)	S	5	5	5
460	OT Management (3)	S	10	10	5
461	OT Research (3)	S	3	15	15
TOTAL HOURS			120	245	150
Table 1	Course names, numbers, and technology codes (S=Support of Therapy; D=Direct therapeutic intervention) and technology related hours spent in lecture and lab formats as well as time in outside assignments.				
KEY	C=CODE; L1=LECTURE; L2=LAB; A=ASSIGNMENT				

TECHNOLOGY COMPETENCY	COURSES
1. To link consumers with information resources.	331, 460, 461
2. To describe methods to actively involve consumers in the evaluation and application process.	460, 461
3. To define technology terminology.	151, 331, 341, 440, 441
4. To describe methods for applying and integrating technology to improve functional performance of clients across the lifespan and functional levels.	151, 330, 331, 340, 341, 342, 440, 441
5. To describe basic technology troubleshooting strategies.	331, 440
6. To describe the application and incorporation of technology within OT theories of practice.	310, 312, 340, 341, 342, 440, 441
7. To describe mechanisms and strategies for technology reimbursement.	151, 320, 331, 440, 461, 470
8. To describe the policies and impact of key legislation.	331, 440, 460, 461, 470
9. To describe theoretical models from other fields related to technology.	331, 460
10. To identify services for clients whose needs exceed services.	331, 460, 461
11. To describe potential roles and qualifications of the team.	331, 460, 461
12. To demonstrate basic use of information management technology.	320, 331, 340, 341, 342, 380, 440, 441, 460, 461, 470, 480
13. To define terminology related to computers and computer-based technologies.	320, 330, 331, 340, 341, 342, 380, 440, 441, 460, 461, 470
14. To demonstrate basic troubleshooting techniques.	331, 440, 470
15. To evaluate, select, modify, and adapt daily living technology.	151, 331, 340, 341, 342, 440, 441, 461
16. To perform activity analysis, feature analysis, and problem solving techniques for comparing strengths and weaknesses.	330, 331, 341, 342, 440, 441
17. To describe potential benefits and limitations of technology as applied to individual clients and settings.	331, 340, 341, 342, 380, 440, 441, 460, 461, 470, 480
18. To describe ethical dilemmas and issues posed by technology within daily environments.	340, 331, 341, 342, 440, 441, 461
19. To describe psychosocial implications of technology within daily environments.	340, 331, 341, 342, 440, 441, 461
20. To analyze critically and apply current research.	320, 440, 461, 480
21. Describe the potential strengths and limitations of knowledge.	320, 331, 461
Table 2	Technology (the term "technology" includes rehabilitative, assistive, and commercial technologies) Competencies for Occupational Therapists: Foundation Level (6) with corresponding OT course numbers.

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HEART - A STUDY ON ASSISTIVE TECHNOLOGY IN EUROPE

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ABSTRACT

HEART is a study of different aspects on assistive technology in Europe, under the TIDE (Technology Initiative for Disabled and Elderly People) programme in Directorate-General XIII in the Commission of the European Communities. The work is carried out by a Consortium of 21 members from 12 countries under the leadership of The Swedish Handicap Institute as Main Contractor.

At the time of writing, the study has completed its first six months, out of eighteen in total. The first period has been devoted mainly to administrative preparation, planning, methodological development and data collection. By the time of presentation, results will have been produced in 32 reports.

BACKGROUND

HEART (Horizontal European Activities in Rehabilitation Technology) is a study of different aspects on assistive technology in Europe, under the TIDE (Technology Initiative for Disabled and Elderly People) programme in Directorate-General XIII in the Commission of the European Communities.

The HEART study is carried out by a consortium made up of 21 institutions, organizations and companies under the leadership of The Swedish Handicap Institute as Main Contractor.

The overall objectives of the study are:

- to survey, analyze and assess the current situation
- to spread information about the current situation
- to create communication channels between actors in Europe
- to show routes to facilitate the creation of a single market by proposing directions and priorities.

The ultimate goal of the study is to improve the life situation for persons with disabilities and elderly persons. Products should have a high quality and utilize current technology. They should be accessible and affordable. Users must have purchase power and influence at different levels. There should be a general accessibility for persons with disabilities to products and services offered in society.

The study covers six areas, or lines. Each line has a designated Line Leader and line members. The Line Leaders and the Main Contractor form the Management Committee for the study. The study started on April 1, 1993 and will finish by October, 1994.

METHODS

The first six months of the study have been dominated by organization, planning, preparations and preliminary collection of data and facts, for which a number of methods have been used. The consortium has established a common terminology and definitions. Data collection procedures have been coordinated. Interdependencies and areas of common interest between two or more lines have been identified and approached.

In order to attain a higher coherence in the study, some common areas to be studied in all lines have been selected. They are: user involvement and influence, wheelchairs and new media.

A Consumer Board has been established with the purpose of facilitating a direct dialogue between the HEART consortium and the users of assistive technology. It is comprised of one representative of each of six major organizations of disabled people.

RESULTS

The results reported in the first round of deliverables contain a wealth of information about rehabilitation technology in Europe. Much of it is new information, information never compiled before or information previously not easily accessible.

Line A: Standards, testing and certification/ specification of rehabilitation technology

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A survey of laboratories involved in testing assistive technology in Europe has been carried out. Forty-one laboratories in 13 countries reported that they are involved in testing assistive technologies. The largest number of laboratories identified is found in Germany, with six laboratories, and the United Kingdom, with five laboratories. The geographic spread is rather wide, but no laboratories have been identified in Luxembourg, Portugal, Spain or Greece.

Existing standards and current standardization work in assistive technology were surveyed. The work resulted in a complete list of all existing national, European and international standards and current standardization work in assistive technology. At the international level (ISO and IEC), around 30 standards exist and another 50 are drafted and planned in the work programmes. Most of them concern technical aids for personal mobility and orthoses and prostheses. 17 standards or draft standards deal with orthoses and prostheses, 23 with wheelchairs. European (CEN and CENELEC) standardization work in the assistive technology field covers at present nearly 40 draft standards, or standards planned in the work programmes. The national survey shows a very mixed picture. Most of the standards are equal to or based on international standards.

Information technology and telecommunications: At the international level, no existing standards were found. Only three drafts and several Work Items were found. Neither were any existing standards found at the European level. At the national level some existing standards were found which concern Braille Graphic Characters and orientation aids.

A general model for user influence in standardization work has been developed. A field trial with user participation in the standardization process has started. The group of products to be standardized is telephone keypads.

Line B: Coherence between and among rehabilitation technology industrial sectors

Information on links, networks and other contacts among assistive technology industries, mainstream IT&T industries, and non-industrial organizations has been gathered through literature searches, interviews and an extensive questionnaire.

A remarkable amount of cooperation was found in specific countries and regions (Northern and central part of Europe) but much less in other countries and at a pan-European level. Networking, in particular, seems to be a powerful tool to improve the situation of smaller companies. The direct involvement of end users is generally weak but some significant exceptions were found. There are numerous links between mainstream IT&T industries and assistive technology companies in research and development activities.

Line C: Rehabilitation Technology Service Delivery

Relevant aspects and characteristics of service delivery systems were identified. A search for literature and other information about the service delivery systems in the 16 countries under study was made.

For each country, there will be a general description of the assistive technology service delivery system or systems. In addition, the procedure for the provision of five selected product categories will be described in detail: manual wheelchairs, telephones for the deaf, computer peripherals for the blind, hygiene aids, and augmentative communication devices.

Draft descriptions of the systems in all the countries under study were made. National contacts in each country completeted and corrected the information. One or more national organizations of the disabled studied and commented on the national descriptions. The result is a compilation of detailed descriptions of assistive technology provision systems in a large number of European countries.

Line D: Legal and Economic Factors Impacting Rehabilitation Technology Availability

A census of legislation affecting the availability of assistive technology products has been made. Legislation was studied in 11 countries in the following areas: Daily living, Education, Working life and vocational training, Social protection, Transport, and Housing.

There are considerable differences in the policies adopted towards legislation for the elderly and disabled in the countries studied. However, there are also a number of common themes. In terms of specific legislation, three broad models have been identified. Different philosophies behind the legislative approaches have been found, as well as a distinction between the legislative bases for the provision of medical devices and the provision of assistive devices.

A theoretical study of microeconomic concepts and a survey of existing socio-economic models has been performed. Three kinds of microeconomic models were identified: Cost-Benefit, Cost-Efficiency, and Cost-Utility. The main advantage of these models is that they permit social aspects to be integrated in economic models. However, the application of these models is limited. In fact, they are specific to a product or to a target group or to an economic actor.

Only a few studies were found in the survey and the ways of describing outcomes differ. Comparisons seem to be very difficult to accomplish, unless standardization is at hand, but there is a long way to achieve this. Cost-effectiveness comparisons based on quality of life cannot be made today. There is one unique way out of the problem, the use of cost-utility analysis. Some studies using cost-utility analysis are available in the field of assistive technology.

Line E: Rehabilitation Technology Training

A survey of existing training programmes for engineers/technicians and related professions (therapists, physicians, teachers, etc, with an emphasis on occupational therapists) in Europe and North America has been carried out.

Pre-service training in assistive technology of technicians and engineers in Europe was mainly identified in two European countries: United Kingdom and Sweden. In Italy, The Netherlands, Portugal, Spain and Denmark, some components of assistive technology training are incorporated in courses at a university level.

In North America, several universities with pre-service training in assistive technology for technicians and engineers, mainly at a Master's level, were identified.

Line F: Emerging Areas of Potential Rehabilitation Technology Research and Development

The following actions have been taken and reported:

Selection of functions to be performed for social integration and technologies to be considered in the study.
Selection of application scenarios - environments which will change significantly in the near future, due to changes in technology or other causes.
Assessment of the present situation in assistive technology: what support is currently available to people?
Identification of the problems of people with disabilities in performing the selected functions with the technical support presently offered.
Identification of developments in assistive technology and in technology not used in applications for persons with disabilities, but with a potential impact.
Identification of possible impact of these developments on the situation of people with disabilities and elderly people.
Identification of critical issues that could influence technology transfer in assistive technology.

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CONSIDERING QUALITY IN A CROSS-DISCIPLINE REHABILITATION ENGINEERING SERVICE

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Abstract
In response to demands/expectations of clients providers of rehabilitation engineering services must become quality conscious and apply the same quality-generating tools that are becoming commonplace in manufacturing industries: Quality Function Deployment, Concurrent Engineering, Continuous Process Improvement, to name a few. Quality techniques are being investigated in a rehabilitation engineering service that manufactures customized mobility and seating. The aim of the research is to: (1) ascertain how these techniques can be best applied in a cross-discipline rehabilitation engineering team and, (2) develop measures of outcome for the client which reference the inputs to the rehabilitation engineering process as well as the quality of service and products supplied to the client. Initial results show Quality Function Deployment and Concurrent Engineering offer considerable benefit to a cross-discipline team endeavouring to increase service and product quality.

Background
Quality is a catchword of the 90's. Consumers demand quality in goods and services; but what is quality? How should it be measured? Garvin [1] has considered five approaches to defining quality: the Transcendental approach of philosophy, Product-based approach of economics, User-based approach of economics, marketing and operations management, Manufacturer-based approach, Value-based approach of operations management. These approaches have relevance to rehabilitation engineering service providers whose clients have rights to receive quality services and products. Purchasers of rehabilitation engineering services are increasingly discerning and apply the same purchasing decisions they apply to other consumer products. Rehabilitation engineering service providers who manufacture customized devices (e.g seating and mobility devices) for clients, particularly severely disabled clients, face difficulty in ensuring the outcome for the client is optimum and matches goals that have been agreed to by client (or carer) and the rehabilitation engineering team. Deviation from prescription or design specification decreases the quality of outcome for the client, and portends loss of revenue and loss of future business for the service provider.

Objective
The objective of this study is to determine what quality techniques can rehabilitation engineering services employ that will increase the likelihood of success in the provision of a technological solution to a client's physical problem or difficulty?

Approach
A rehabilitation engineering team has been investigating some techniques used in contemporary engineering practise to evaluate their usefulness in rehabilitation engineering.

<u>Flowcharting</u>
Flowcharting involves mapping the inputs, inventories, outputs and activities that occur in rehabilitation engineering practise and linking the various components to show flow of the process and relationships. From a flowchart can be gleaned (1) a critical path of elements or activities that must be in place in order to avoid delays, (2) labour and time requirements for activities, (3) the inter-relationships of the process, (4) possibilities for improvements in service delivery, (5) cost structures.

<u>Quality Function Deployment (QFD)</u>
QFD is a methodology for selecting and prioritizing quality requirements of the customer, converting requirements into technical/design criteria and systematically utilizing these criteria to drive the product/service process to achieve the customers' requirements [2,3]. QFD is a powerful technique for identifying and integrating disabled clients' requirements for quality into the processes and activities of the rehabilitation engineering effort.

<u>Concurrent Engineering (CE)</u>
Concurrent Engineering describes the concept of integrated, simultaneous design of a product and its related processes, e.g. manufacture, testing.[4] CE embodies a team approach to problem solving.

The combination of QFD and CE is a powerful tool for rapidly producing customized devices with quality and features meeting the requirements of the disabled client.

These techniques are being utilized in a seating clinic which has operated for many years with limited resources. This clinic manufactures customized mobility and seating devices for adults and children with severe disabilities. A large backlog of work threatened to overwhelm the facility and staff, prompting an analysis of the modus operandi of the team.

Analysis of video recordings of client assessment sessions (which operated on a medical model at the time) revealed this method of operation was insufficient to acquire the extent of information necessary for understanding the client's requirements[5].

Flowcharting revealed the clinic was not making best use of labour resources by seeing clients for short fitting sessions between bursts of manufacturing effort. Members of the cross-discipline team (rehabilitation engineer, orthotist, physiotherapist, occupational therapist, technician) were frequently absent from important processes: assessment, prescription decisions and trial fitting of manufactured devices. Important skills and information input were missing from processes which had a direct bearing on design, manufacture, outcomes and overall quality.

Equipment manufactured by the clinic was frequently not sufficiently robust to withstand the rigours of use, particularly in large residential care institutions. Designs, materials of manufacture did not reflect client and carer needs in equipment such as tilt-in-space, lightweight, compact, easy to use.

Results

Major changes were made to the clinic reflecting an emphasis on the outcome for the client. This list is interim as research into quality aspects of service delivery is on-going:

1. Medical style assessments were replaced with a format which aimed to acquire pertinent, accurate information and data about the client and their environment in which prescribed equipment would be used. The importance of the team has been engendered in assessment technique.

2. Client evaluation, prescribing, decision making, design, manufacture and trialing were programmed to occur on one day, occupying the whole day. Flowchart and resource analysis indicated 2 clients requiring this level of input could be completed per week.

3. Documentation was developed to match and prompt the progress of the assessment process for detailed, accurate information and data gathering.

4. Goals for the equipment and the client's use of it were established by the team, elucidated to client (or carer) and used comparatively during the operation.

5. QFD techniques[6] were employed (and continue to be) to sort information from disabled clients about equipment features that need to be designed in and how this should be done.

6. CE practice was introduced to speed up production. Where possible design and manufacture are performed as parallel activities instead of serial activities. The program aim is for the client to leave the clinic at the end of the day with a device to trial at home for a week, to isolate defects and operating difficulties before completing manufacture (e.g. upholstery).

Discussion

Application of contemporary engineering process and quality techniques, facilitated by willingness of team members to reflect on the results of analysis and make changes has significantly improved productivity of the clinic. A service that had a backlog of work approaching 12 months is now able to clear 200 clients per annum, manufacturing 130 major and 55 minor devices (1993 output).

Video analysis of client assessments, team discussions and decision-making is particularly useful for revealing loss of information that is relevant to the client's situation and requirements. Information capture, the assimilation and comprehension of this information and its manipulation or conversion into technical data is crucial to the success of downstream activities such as rehabilitation device design and manufacture. Good documentation of client information, assessment findings, team discussion and decisions in a format that is readily discernible by professionals from physical sciences and life sciences helps accuracy and reduces the likelihood of misinterpretation.

Some client data is best kept visual as it involves mimicry or similar highly visual detail. A photograph does not capture the motion of this detail and attempting written description loses both content and context. The retention of video data (video clips) in a client's file on a computer database is being examined. A major detraction is the time required to edit the video to find pertinent frames of video plus appropriate memory to store video data for rapid retrieval by computer (writeable CD ROM has application).

QFD's power in rehabilitation engineering is in:
(a) converting client quality and design features into engineering considerations with analytical connotations for inclusion in product design and,
(b) providing a mechanism for assisting the inclusion of client-inspired quality features at each stage of the rehabilitation engineering process. This could be a vital tool in rehabilitation engineering because able-bodied designers often do not recognize subtleties unique to disabled persons which must be accommodated in devices.

Rehabilitation engineering is a fertile area for unique application of quality techniques. The team approach has been well established in rehabilitation engineering, particularly where a service has been founded on a medical model. QFD and CE being team-centred techniques lend themselves to being utilized in rehabilitation engineering. It must be recognized that QFD, CE and other quality techniques were developed for large volume manufacturing industries (consumer products such as automobiles, refrigerators). Modification of these engineering quality techniques is necessary to accommodate both physical science and life science nature of the disciplines associated with rehabilitation engineering teams and the one-off nature of device development and manufacture.

Conclusion

Our work so far has found that quality techniques applied to a cross-discipline team rehabilitation engineering service work favourably and help the team achieve a level of quality in client services that a conventional medical model team has been unable to achieve. Tools such as QFD and CE developed for manufacturing industries require adaptation for application to the type of group found in rehabilitation engineering.

Future Work

An in-depth study has commenced of the moment-to-moment activity, communication and process during client assessment, team decision-making and design/manufacturing tasks in a seating clinic, using video, observation and examination of case notes.

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REHABILITATION ENGINEERING TRAINING - THE PRACTICAL SIDE

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ABSTRACT

This paper presents the practical side of a one year masters level training program. It addresses how a diverse group of students are being prepared to provide applied engineering skills. Course contents and how practical aspects are employed are discussed. The results of an internship utilizing a Rehabilitation Engineering Service are also presented.

BACKGROUND

Rehabilitation Engineering educators in the United States are in the process of defining educational goals, learning experiences, and performance expectations. At the 1993 RESNA Annual Conference, a diverse group of engineering educators and interested parties met to share concerns and ideas. They decided that a workshop on Rehabilitation Engineering Education should be held to pull together the growing Rehabilitation Engineering education community, produce stronger educational programs, and identify the educational requirements needed to attract, retain, prepare, and graduate Rehabilitation Engineers to meet the increasing challenge of applying complex technology to the needs of individuals with disabilities. Some of the training issues may focus on knowledge in life science, human factors/ergonomics, applied engineering, rehabilitation service delivery systems, and an internship experience. This paper discusses the approach and experiences in teaching the practical side to students in the masters level Rehabilitation Engineering Training Program at Wright State University (WSU). Hopefully this will be of assistance to other students, educators, and the workshop participants when it is held.

In a previous paper, the four quarter, one year program in Rehabilitation Engineering Training at WSU was described (Rowley). Over the past two years eleven students have graduated and this year six more will complete the program. There are also several part time students. Three graduates are working at rehabilitation centers, one started a rehabilitation engineering company, one went to medical school, one is completing a military obligation, one is the ergonomist for a division of an automobile company, two are consultants, one works for a prosthetics firm, and one is working in a family business. They entered the program as engineers with biomedical, human factors, electrical, mechanical, and engineering physics backgrounds. Three came from industry, two from other graduate programs and the others immediately from their BS programs. The full time students the first year were four men and one woman; the second year, four men and two women; and the third year, one man and five women.

METHOD

The Practical Side

To meet the challenge presented by this diverse group of students, analytical and applied courses have been developed so that all will have a similar set of skills and experiences upon graduation. The students are expected to enter the program having already taken courses in anatomy and physiology. The analytical courses are:

- Advanced Biomechanics
- Applied Statistics
- Bioinstrumentation
- Biomechanics
- Biomedical Computers
- Neuromuscular Rehabilitation
- Robotics

The applied courses are:

- Human Factors Engineering in Rehabilitation
- Introduction to Clinical Practice
- Introduction to Rehabilitation Engineering
- Introduction to Rehabilitation Design
- Rehabilitation Assistive Systems
- Rehabilitation Engineering (the internship)
- Rehabilitation Egr Computers
- Rehabilitation Egr Design
- Rehabilitation Egr Service Delivery

These focus on communication skills, social skills, team skills, applied computers, applied electronics, applied mechanics, and applied ergonomics. Within these courses the students learn about assistive technology: wheelchairs, seating, driving, augmentative communications, and computer adaptations. They learn how to apply basic engineering building blocks such as CMOS devices and four bar linkages; the range of disabling conditions: CP, MS, SCI, amputation, head injury, aphasia, etc.; and how rehabilitation delivery service works. By the third quarter they are receiving applied instruction on home and workplace modifications, meeting the needs of rehabilitation counselors and their clients, and receiving an introduction to a rehabilitation center; they will have evaluated, designed, and constructed electronic and mechanical devices, produced at least three major reports and made numerous presentations; and as teams they will have designed and delivered several solutions to problems for individuals with disabilities.

Through out the year field trips help bring to focus class room instruction. These trips involve vehicular modifications, an industrial setting for the blind, a workmens' compensation rehabilitation center, schools and assembly lines at a county MR/DD board, prosthetics and orthotics manufacturing, a rehabilitation center, a center for augmentative communications and computer adaptation, a truck plant with an aging work force, the Ohio Rehabilitation Technology Association meetings where case studies are presented, and the RESNA annual conference.

Guest speakers are invited to present in the Introduction to Rehabilitation Engineer, the Rehabilitation Engineering Systems, and the Introduction to Clinical Practice courses. These speakers come from the medical profession, vocational rehabilitation, services for the blind, services for the deaf, county boards for MR/DD, workmens' compensation rehabilitation division, and practitioners within rehabilitation service delivery.

Instructional Resources

The following texts have been used with the applied courses.

"Americans with Disabilities Act Handbook", Equal Employment Opportunity Commission and the U.S. Department of Justice

"Augmentative Communications an Introduction", American Speech-Language-Hearing Association

"CMOS Cookbook", 2nd ed., by Lancaster, Revised by Berlin, SAMS

"Cumulative Trauma Disorders: A Manual for Musculoskeletal Diseases of the Upper Limbs", by Bristol, Taylor & Francis, Inc.

"Electronic Devices for Rehabilitation", by Webster, et. al., Wiley Medical

"Fundamentals of Industrial Ergonomics" by Paulat and Mustafa, Prentice-Hall

"Mechanism Design Analysis and Synthesis Volume I" by Erdman and Sandor, Prentice-Hall

"Positioning for Function", by Bergen, Presperin and Tallman, Valhalla Rehabilitation Publications, Ltd.

"Using Toolbook" and "Using OpenScript", Asymetrix

The students also receive course handouts which have been developed by the instructors. Subjects include disabilities, medical aspects, service delivery, vehicular modifications, assessments, wheelchairs, the ADA, the Rehabilitation Act with Amendments, and the Technology Act. There is also an adapted computer laboratory on campus with the latest technology installed and working. In the Rehabilitation Engineering Laboratory (REL) are examples of augmentative communications devices.

Each student is provided a large filing drawer within the REL and encouraged to start building their own library using the REL resources as a guide. These resources include pamphlets from manufactures, catalogs, proceedings, journals, and books on rehabilitation and engineering. A few of these are Assistive Technology, Augmentative and Alternative Communication, Journal of Rehabilitation Research and Development, IEEE Transaction on Rehabilitation Engineering, Technology and Disability, Technology Aid to the Disabled Journal, Closing the Gap, Solutions-access technologies for persons who are blind, Technology for Independent Living Sourcebook, Recreation-Oriented Assistive Device Sources, Choosing the Best Wheelchair Cushion, Design Engineering Handbooks, and Hyper-AbleData.

The Practical Internship

This capstone course as previously described has been restructured to give the students an improved experience providing rehabilitation engineering service (Rowley). The clinical task list is still required and has been improved upon with the help of the rehabilitation center staff. The students are still graded upon attendance, completion of the clinical tasks, and their designs. The major change is how the internship is organized and managed. Each day is now divided into two parts. The mornings are devoted to the clinical tasks, rounds, and rehabilitation teaming. In the afternoons a Rehabilitation Engineering Service (RES) is operated. The RES responds to the needs of the rehabilitation center staff: inpatient and outpatient services; home health care, and industrial evaluations; computer, wheelchair and driving adaptations; and equipment modifications.

This past summer 51 projects were considered by the RES. Forty-three of these entered the preliminary design stage, 33 were designed, and 17 were completed and delivered. Some of these were an automobile simulator for transfer training, adaptive equipment setup for a person with SCI, a set of adaptive switches, modification to a fluoroscopy chair to aid swallowing evaluations, a new fixture for the Baltimore Test Equipment Work Simulator to provide therapy for vertical motions, a simulator to train patients to use the Life Line, and a putting green.

In addition, each student completes at least two home visits, one workplace evaluation, and one service call for vocational rehabilitation. The student prepares the reports that are given to the counselors. They also participate in presenting a workshop for rehabilitation counselors. This serves as practical application for their communication skills and helps increase their networking base.

DISCUSSION

The practical side of this training program develops the applied skills of the Rehabilitation Engineer. Communications are honed through reports and presentations. Engineering skills are developed through courses with real life application requirements; students learn by doing. Networking, so important for developing a service practice, is begun through field trips and guest lectures. Students are exposed to a large number of individuals with disabilities and are required to become very familiar with the service delivery system, how a rehabilitation center functions, and the delivery of service in the home and workplace setting. They graduate with a set of experiences that prepare them to apply technology to the needs of rehabilitation service agencies, schools, industry, providers, and individuals with disibility.

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IN-SERVICE AND CONSUMER TRAINING IN ASSISTIVE TECHNOLOGY: A WORK IN PROGRESS

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ABSTRACT

Due to the interdisciplinary nature of Assistive Technology training, there are few professional pre-service training programs in colleges and universities. Maryland's Technology Assistance Program's response uses a multifaceted training-consultant model. Training is offered in each region of the state and covers topics including sensory aids, cutting edge technologies, funding, recreation and leisure, environmental modifications and technology for kids. Evaluations and needs assessment are done of each training program to insure quality of the training and continued improvement, or development of new programs.

THE PROBLEM

Assistive Technology training encompasses the skills and knowledge of many different disciplines: including occupational therapists (OT), physical therapists (PT), speech therapists, engineers, teachers, nurses, physicians, rehabilitation counselors and computer experts. Even so, there are surprisingly few assistive technology (AT) concentrations in professional pre-service training programs. Courses are offered in programs for occupational therapists, nurses, engineers, physical therapists and speech therapists. Some special education programs have a course in AT. There are bio-medical engineering programs but entire programs for rehabilitation technologists are few. In reviewing lists developed by Training Programs in AT (1992) (1) and Technology Training: Resources for the Trainer (1990) (2), no programs were listed as offering degrees. Courses were found as parts of professional training programs. There are few exceptions to the above. Johns Hopkins University offers a degree in assistive technology for educators. The University of Wisconsin-Madison offers several degrees in rehabilitation-related fields with training in assistive technology. The University of Pittsburg is planning to institute a new department called Rehabilitation Science and Technology. Presently, a certificate is offered to Occupational Therapists (OT), Physical Therapists (PT), Engineers, and Biomedical Engineers. (Brienza 1994). A recent literature search found very little published information about what kind of training is being done at the professional level in assistive technology.

One might ask, "Why the focus on professionals?" Peterson, MacArthur & Brady (1991) (3), researchers in Maryland found that most consumers of AT learned about their devices from medical service providers.

NEW APPROACH

Maryland's Technology Assistance Program has responded to the needs for training of professionals by using a multifaceted consultant model. Generalists with expertise in a focal area develop two hour training modules. Each module is offered several times a year in different regions of the state. In this way all training programs are avilable within a reasonable commute to all citizens in the state.

Consultants available through the business community, and organizations such as RESNA, are utilized where needed. Outside their focal area of expertise, staff members are encouraged to attend these training programs, along with members of the community. In this way, a broadly-based consultant network is reinforced, as all staff members acquire knowledge of additional areas of technology.

Technology seminars cover topics of sensory aids, augmentative communication devices, funding for assistive technology, technologies for adaptive recreation and leisure, technology for kids, environmental modifications, and "cutting edge" technologies.

Educational approaches are designed for the adult learner and many programs use a hands-on, as well as a lecture format.

Each program is evaluated on content and presentation. Data is kept on attendance and consumer satisfaction. Part of the evaluation asks the audience what they would like in future training programs. In addition, needs assessments are conducted in conjunction with state agencies, and both private for profit and private not for profit rehabilitation facilities, persons who deliver services, and concentrated populations of consumers of services, such as elder homes.

Goals for 1994 include the development of modules in each of the areas of training mentioned above. These modules will be available in multiple formats including audio tape, disk and large print. An outline of course content and audio description of overheads or slides will be a part of the module.

FUTURE DIRECTIONS

Other long term goals of the training program are to better utilize media such as satellite, cable T.V., radio networks, and other distance learning technologies.

Training for professionals, both pre-service and inservice, is an ongoing process. Providing relevant and successful AT training in a cost effective manner remains a significant challenge for the field, and a major focus of many Tech Act programs.

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HOME SYSTEMS TECHNOLOGY FOR ELDERLY AND DISABLED PEOPLE PRESENT STATUS, R&D METHODOLOGY AND FUTURE DIRECTIONS

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ABSTRACT

The ability to perform everyday tasks, in the home, is a major need expressed by a large number of elderly and disabled people. The independent living that this leads to is aspired to by many. Although environmental control systems have traditionally been used to help them meet this need, several advantages can be identified if general home systems technology, with suitable user interfaces, is employed instead. This paper identifies the major issues in this approach, presents a brief overview of the state of this technology, discusses the requirements in terms of R&D methodology and outlines future directions in this area.

BACKGROUND

The needs of disabled and elderly people in the home are essentially the same as the needs of us all. However the way these needs are met may have to be different. A large number of disabled and elderly people need assistance for such common actions as switching on the lights, controlling white and brown goods, and many other simple tasks. This situation limits their independence in daily living, a problem that traditionally has been minimised by using environmental control systems. However, since each manufacturer develops its own proprietary solutions, adding new devices to the system is frequently not as simple as it should be. Lack of interoperability prevents higher manufacturing volumes and the limited scope of these systems make them not attractive to the general public (further contributing to increased prices).

Market issues are indeed one of the most important questions that have to be addressed, since cost is usually the ultimate factor that determines whether or not a good product is successful in this under resourced sector. It is interesting to note that the single objective of the European TIDE (Technology Initiative for Disabled and Elderly people) programme has been stated as to "stimulate the creation of a single market in rehabilitation technology in Europe" [1]. Market issues in this area can only be successfully addressed if the manufacturers agree to work within defined standards, in order to assure equipment interoperability and low prices. Rehabilitation technology developed to improve independence at home can only meet these objectives if the wider technology domain of "home systems" is adapted to the specific requirements of disabled and elderly people.

A Home System (HS) specification defines a "comprehensive communication system inter-connecting several kinds of electronic products used within the home" [2]. A commonly accepted, non-proprietary HS specification will ensure interoperability of equipment regardless of the manufacturer and at the same time will contribute to wider public acceptance. The market for HS products has however consistently been under most expectations essentially due to a lack of an internationally accepted standard [3]. This is still a largely unsolved issue, since different development directions were followed in Japan, US and Europe.

Japan is probably the country where HS technology is more coherent, since the first activities were initiated as early as 1980 by the Institute of Electric Engineering of Japan [4]. A home bus study committee was set up in 1982 and the Home Bus System (HBS) standard was published in 1988. Over one million HBS standard systems are now installed in Japan.

A less coherent approach is found in the US, where such different systems as the Smart House, CEBus and de-facto standards as X-10 and Echelon are available [3].

A number of specifications are also available in Europe, including Batibus and Instabus EIB [5]. The work towards a common European HS specification started in the late 80's, but the main effort started only in 1989 with an ESPRIT (European Strategic Programme for R&D on Information Technology) project entitled Home Systems (EP 2431), which released the first version of the ESPRIT HS specification. Approximately one dozen ESPRIT projects are currently active in this domain, involving more than 50 companies developing Conformance and Development Tools as well as Software and Hardware Modules [6]. Version 1.1 of the HS specification was released in 1992 by the European Home Systems Association (EHSA), which was founded to promote and support the development and standardisation of this specification.

STATEMENT OF THE PROBLEM

General HS technology, according to the definition presented in the previous section, aims to achieve two main goals [7]:

- To enable a service requiring several products to work together (which identifies the need for clusters of interconnected products)
- To provide a simple way to operate sophisticated products (which is indeed one of the major consumer concerns)

A HS able to fully meet these two requirements will provide three major benefits to the user:

- It will allow remote control over much of the equipment within the house
- It will allow several products to perform some type of co-ordinated operation or service (security, for example, may require the co-ordinated operation of different products, which may however be also used for other purposes)
- It will make possible a true modular functionality, where products can be added or removed at any time

Work done in this field in the last five years has produced the specifications of a flexible hierarchical architecture, and a communications network, which are able to provide these three benefits [2].

The practical advantages for the common consumer are of three main types: added comfort, improved security / safety and economy (mostly due to optimised energy consumption). However, for many disabled and elderly people, the important issue is that HS technology is capable of improving their independence in daily living, which definitely represents an important contribution to their quality of life. Moreover, and since HS technology addresses the general consumer electronics market, it brings the additional benefits of low-cost and wide availability products. Allowing the community of disabled and elderly consumers to fully benefit from these promises can, however, be ensured only if two main requirements are satisfied:

- The range of HS-compatible products available must be able to satisfy their specific requirements
- The range of user interfaces available must be compatible with different types of disabilities

APPROACH

The R&D methodology underlying any HS project aiming to meet the two requirements specified above can be summarised in one single statement:

- Led by the end user's requirements and not by the technology.

Moreover, and since these two requirements generate R&D tasks that can proceed in parallel, the approach to develop effective rehabilitation technology products in this area must include four main activities, in time order:

- Identification of the end user requirements: The multi-disciplinary team responsible for this work must relate the requirements of their specific end user groups to all the information already available from other projects [8,9]
- Technical specification: Again led by a multi-disciplinary team, this activity represents a first opportunity for system validation, since rehabilitation technology professionals and end users are provided with a formal specification of the proposed solutions
- Applications and user interfaces development: This activity includes the two main R&D tasks corresponding to the requirements set up in the end of the last section. It is mainly an engineering led activity, although end user involvement is essential to provide guidance on many implementation details. Unnecessary duplication of R&D efforts can be assured by a proper survey of previous work, both in the general HS technology field and in previous projects specifically concerned with the adaptation of HS technology to disabled and elderly users [10]
- Evaluation: This activity comprises the implementation of solutions at end user sites, which must be accompanied by an adequate training program. A formal evaluation methodology will then enable the assessment of benefits [11]

End user involvement is a key issue throughout all activities, since it is essential to guarantee that the developed solutions are effectively led by end user requirements and not by technology driven factors. In response to an open call for proposals set up during 1993 within the European TIDE programme, a two and a half year project following this approach was selected for funding by the Commission of the European Communities. Started in January of 1994, this project is entitled HS-ADEPT (Home Systems - Access of Disabled and Elderly People to this Technology) and involves end user organisations, R&D institutions and industrial partners from four European countries. The workplan of the HS-ADEPT project closely follows the four main activities previously described.

IMPLICATIONS

The implications of HS technology in the daily life of many groups of disabled and elderly people extend over a wide number of issues, the most important of which is however its very significant contribution towards greater independence. This is indeed a key issue, with further implications which range from the end users (improved self confidence, better quality of life, etc.) to the State itself (in terms of social support measures, financial issues, etc.). It is also important to note that the benefits of adapting HS technology to the specific requirements of disabled and elderly people, by making use of technologies and products addressing the wide consumer electronics market, effectively contributes to increase the awareness towards the importance of a single market in rehabilitation technology products.

DISCUSSION

This paper has identified the major issues concerning HS technology for disabled and elderly people, presenting a brief overview of the state of this technology and discussing the requirements in terms of R&D methodology. It is however important to refer that HS technology, both for disabled and elderly people or for the general public, is still in its infancy. This is not only in the acceptance of internationally adopted standards, but also in the extraordinary potential that will result from the marriage with advanced telecommunication networks, namely the Broadband Integrated Services Digital Network (B-ISDN) [12]. This marriage will enable the development of a wide variety of telematic services, ranging from entertainment to education and tele-working. The multi-billion dollar market associated with sophisticated interactive video services will become a reality in the medium range future (10 to 20 years say, depending on government regulations, world-wide standardisation efforts, etc.), but it is as yet unclear whether it will be possible to guarantee that this huge technological leap forward will contribute to yet further barriers for disabled and elderly people or be made accessible to them.

It seems clear that it is possible to adapt HS technology to the specific requirements of people with special needs and still benefit from its success in the general consumer electronics market, but a large effort will certainly be required to make sure that the next step in this (r)evolution will accommodate requirements other than those of the perceived mass markets.

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ACCESSIBILITY STANDARDS FOR CHILDREN'S ENVIRONMENTS

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ABSTRACT

Despite obvious physical differences between children and adults, child care centers, pre-kindergartens, elementary schools, and other facilities used primarily by children are required to be built according to accessibility standards developed for an adult population. This paper describes the results of a project to identify the accessibility needs of children of different ages with a range of mobility and visual impairments, and to evaluate the suitability of accessible features built to different technical specifications. Information was obtained through direct observation of children with disabilities using accessible features as well as through group interviews with children and adults. Accessibility needs were found to be dependent on personal factors, both developmental and disability-related, such as fine motor ability, upper body strength, extent of reach, stature, stamina, balance, and skill level in negotiating the environment. In addition, situational factors, such as the number of children with disabilities using a facility, policies and practices regarding the role of adults in providing assistance, and interaction of personal factors and physical characteristics of accessible features also were found to impact accessibility.

BACKGROUND

In child care centers, pre-kindergarten and elementary schools across the country accessibility standards have been applied that were developed for an adult population. Although facilities complying with these standards have met the needs of many adult users with disabilities working in or visiting children's facilities, such facilities have not necessarily met the access needs of children. In 1986, the Architectural and Transportation Barriers Compliance Board (ATBCB) issued its own *Recommendations for Accessibility to Serve Physically Handicapped Children in Elementary Schools* (1986). This was the first major step to address the lack of accessibility standards for children's environments, tailored to children. In anticipation of the passage of the ADA and the need for more comprehensive guidelines for children's environments, particularly those that were to be covered under Title II of the ADA (i.e., public schools), the ATBCB contracted with the Center for Accessible Housing to develop recommendations for enhancing the accessibility of environments used by children of all ages, not just those of elementary school age and not just those with physical disabilities. The scope of these recommendations was to parallel and augment that addressed by ADAAG/UFAS for the adult population.

OBJECTIVES

The purpose of the project was to develop recommendations for accessibility guidelines for children's environments on the basis of: precedents established by existing codes and standards, findings of prior studies, and in-use evaluations of accessible children's environments. This paper reports on key factors impacting the suitability/accessibility of design features for children.

METHOD

Facility evaluations were conducted at nine sites that represented a variety of building types used regularly by children. These included: three preschools, three residential schools for children with vision and orthopedic disabilities, three elementary schools, and a children's museum. All had been built or renovated to be accessible. The sites, collectively, served children of diverse ages (e.g., preschoolers to teens) with different types of disabilities.

The study focused primarily on children age 14 and younger. A total of 107 children were unable to walk and 44 walked with difficulty; 58 had no usable vision and 150 had low vision; 29 were unable to use their arms and/or hands, and 78 had limited use of their arms and/or hands; and 9 had severe hearing loss and 9 had mild to moderate hearing loss. In addition, many of the children had multiple physical and sensory impairments. The children used a wide variety of aids and devices to assist them in moving through the environment; however, substantial numbers of the children at several sites used no aid or device, at least under some circumstances.

Physical measures data (e.g., slope and length of ramps, height of toilets) as well as illustrations and photographs were used to describe and document accessible features at each site. The suitability of as-built features for children with disabilities were assessed with a multi-method approach that involved observational techniques, self-reports of accessibility, and small group interviews. This approach evaluations permitted data to be obtained from multiple perspectives (e.g., self-report of children and/or staff regarding suitability of accessible features, observation by experts of suitability) that may or may not agree in their assessments.

Observational and self-report data were obtained on the suitability of frequently, infrequently and sensitive-use accessible features for children with disabilities. Observation of naturally-occurring use of accessible features was limited to those features that received a high incidence of use at predictable times. Simulations were utilized to obtain observational data for infrequently used and sensitive-use features, such as toilets. Children who participated in the simulated usage portion of the data collection were given simple instructions, such as "show me how you would go about taking a shower." Specific prompts to simulate use were not given unless the child had overlooked them. During the simulations, some children volunteered explanations of what they were doing and why. In other cases, they answered questions posed by the research team related to the simulated activities.

Small group interviews were the primary means of obtaining information from staff as to the suitability of accessible features for children as well as for themselves. Small group interviews also were held with children when, in the judgment of the facility administrator, children could be identified that could meaningfully participate (e.g., old enough, verbal, etc.). The questions asked in the interviews were modified, depending on adult or child group composition.

RESULTS

Although the physical measures and site evaluations focused on a broad array of accessibility features that were likely to impact accessibility for children, those features that were found to be most critical to accessibility for children are highlighted in this paper. These include accessible routes, ramps, elevators, doors, storage and toilets.

Accessible Route: The *width* of accessible routes varied extensively within and across the sites (43" to 138"). Where there were a number of children in wheelchairs who used a pathway at the same time, the wider routes worked well. They helped to avoid congestion and permitted two-way traffic. In addition, because children frequently do not have finely honed skills in maneuvering wheelchairs, the wider routes were compatible with their skill level, and reduced the wear and tear on walls and corners. Finally, in settings used by children in wheelchairs as well as children with sensory disorders, wider routes helped to prevent accidents.

The *length* of interior and exterior accessible routes was also identified as an important issue because many children with disabilities at the study sites had limited stamina. Long accessible routes were common at multi-building sites, and in multi-story buildings. The distance that children had to traverse also was influenced by the placement of ramps and elevators in relation to the points of origin and destination for any specific trip.

Ramps: Where ramps were present, they varied widely in *slope*. Five ramps were steeper than the widely accepted maximum slope of 1:12, ranging from 1:4 to 1:10. Four sites had ramps with slopes that were less than 1:12, ranging from 1:13 to 1:29. Many children, particularly those using manual wheelchairs who had limited strength and stamina, experienced difficulties ascending ramps, even those that were shallower than 1:12. As a result, children were pushed up ramps by parents or staff at several sites.

The clear *width* of ramps also varied widely across the sites (36.5" to 116"). All ramps exceeded the widely accepted minimum of 36", which helped to avoid congestion and accidents at sites where children in wheelchairs traveling in both directions at the same time.

Elevators: Elevators were present at five sites. The *height of call buttons* ranged from 40.5" to 43" above the finished floor (AFF). These heights were too high for many of the children to use easily, if at all. These difficulties appeared to be related to the body stature and reach of children. In addition, children with arm and hand impairments had even more difficulty in reaching controls.

Doors: One of the most pervasive problems for children of different ages and with different types and severity of disabilities was pulling/pushing and holding doors open. *Force* required to operate exterior and interior doors varied widely. The least amount of force required to open an exterior door was 2 pounds force (lbf). More common force measures for exterior doors were between 8 lbf and 16 lbf. Some interior doors required as little as 1 lbf to 3 lbf to open. Interior doors also were found that required as much as 16.5 lbf to open.

Virtually all children, not just those who use wheelchairs or those with gait and balance disorders, experienced difficulty in using doors. This was true for all doors requiring manual operation, although the amount of difficulty encountered appeared to be a function of the amount of force required and the strength of the child. The problem of force required to open exterior doors was avoided at two sites that used sliding doors with electronic/mechanical openers. At one preschool site a motion sensor activated a door opener, although the system could be manually switched off by staff if necessary. At the other site, a power opener was used. These types of doors and openers easily accommodated age- and disability-related differences in the speed at which children could move through doorways.

Storage: The maximum observed *height* for storage used by ambulatory children varied considerably, ranging from a low of 40" at a preschool to a high of 78.5" AFF at a facility used by older children. Notably, storage 43" AFF was too high for older nonambulatory children at another site. The 40" height of the open storage cubbies at the preschool worked well for young children. At one site, some lockers had been modified with a low shelf 5" AFF that worked well for children in wheelchairs with reach impairments. These data indicate that the most appropriate height of storage is influenced by body stature, body position, and forward and upward reaching capabilities of the child. It is unlikely that fixed storage heights will work for a cross section of children. Adjustable shelving of different depths is a viable option to this problem.

Toilets and Toilet Stalls: *Toilet seat height* varied among the sites. The lowest toilets (11" to 12") were found at preschool sites. Sites that served older children and children of different ages and with diverse capabilities to transfer tended to have toilets of a variety of heights. Age and independence in toileting influenced the suitability of different toilet seat heights. Staff reported that the critical issue related to toilet height for young children was to ensure that they were low enough for children to sit with their feet on the floor, which enhanced the children's sense of stability and body functioning. As most young children in wheelchairs were placed on toilets, toilet heights compatible with transferring was less of an issue for this age group. At sites serving older children, toilets seats at 16" AFF permitted them to transfer independently.

Grab bar height varied widely across sites (16" AFF to 42" AFF). Observations at several sites and staff comments suggest that the critical issue in the use of toilet side grab bars by children under 8 or 9 years old or those with disability-related reach limitations is the distance of the grab bar from the toilet, not its height. Different grab bar configurations worked well for children of different stature with different types and severity of orthopedic disabilities. In pre-school facilities, the use of small diameter bars enabled children to easily grasp them.

DISCUSSION

The suitability of accessible features at the study sites were impacted by differences among the children (and between children and adults) with regard to:(1) fine motor ability (such as the operation of controls), (2) upper body strength (such as opening doors), (3) reach in AP and ML planes (such as wall mounted objects or grab bars), (4) stature (such as sitting on a toilet with feet on the floor), (5) stamina (such as climbing ramps), (6) balance (such as maintaining an upright position on a toilet), and (6) skill level in negotiating the environment (such as maneuvering a wheelchair precisely. In addition, the number of children with disabilities using a facility simultaneously, and the policies and practices of the institution with regard to encouraging independence impacted the suitability of accessible features in-use. These factors are important considerations in planning and implementing environmental and technological changes that meet the accessibility needs of children with disabilities. An understanding of how these factors shape accessibility needs and experiences is crucial in the development of technological and environmental solutions to accessibility in children's environments.

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SIG-02
Personal Transportation

Development of instrumentation and protocols to measure the dynamic environment of a modified van

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Abstract. The dynamic environment of a van modified to accommodate a person driving from a wheelchair was measured to determine the effects of position within the van and the type of seat used. The project measured accelerations as a subject sat in 3 positions within the van and upon two different seats. Three separate van maneuvers at different speeds were used to change the dynamic environment. Van accelerations at the different positions varied significantly. A wheelchair transmitted more accelerations to the subject than the original equipment manufacturers (OEM) seat, making it harder to maintain a stable posture. These results should prove useful to others studying the functional abilities of wheelchair users within a vehicle environment.

Introduction. In order to determine the effects of the dynamic environment on the stability and functional ability of a driver with a disability, the forces and accelerations within the driving environment must be understood. A person driving from a wheelchair usually requires modifications to a van, including a raised roof and dropped floor, and a lift. These modifications influence the vehicle's handling characteristics.

Much of the research that has been performed on dynamic vehicular environments focused on vehicles during high performance or emergency maneuvers. Very limited information is available regarding the dynamics of vehicles after they have been modified to accommodate a person seated in a wheelchair. Literature on human reactions in moving vehicles deals almost entirely with able-bodied individuals or crash test dummies seated in the original manufacturer's seating systems.

Objective. The goal of this project was to design instrumentation and testing protocols which could be used to define the dynamic environment presented by a vehicle which had been modified to accommodate wheelchair users. This study concentrated on identifying the effects of seat type and seat position within the vehicle, and quantifying the magnitudes and variation of accelerations during repeated trials. Information collected during this project could then be used to design studies which specifically study the effect of the wheelchair, seating system, and/or van modifications on the stability and function of a wheelchair user in a vehicle.

Methods. The response to the dynamic environment of an able-bodied subject was characterized by the linear accelerations as a function of her position within the van and the seat upon which she was seated. Accelerations were measured with the subject seated in the manufacturer's driver seat, the front passenger seat, and a wheelchair secured in the driver's and rear passenger areas. Subject response was measured by accelerometers secured to the sternum of the subject. Vehicle response was measured by accelerometers secured under the seat of the subject. Acceleration profiles of the vehicle and subject were collected while the vehicle performed several maneuvers outlined below. Maneuvers were selected because they represented common tasks in a normal driving experience.

1. **Acceleration from rest.** Van was accelerated from standstill to speeds of 16.1, 32.2, and 48.3 km/hr (10, 20, and 30 mph) in ten seconds.
2. **Deceleration to rest.** Van was decelerated from speeds of 16.1, 32.2, and 48.3 km/h (10, 20, and 30 miles/hour) to standstill in 4 secs.
3. **Curve Driving.** Van was driven around a curve at constant speeds of 16.1 and 32.2 km/hr.

Data Collection and Analysis. Accelerations were measured using 6 uniaxial accelerometers which had a range of +/- 5 g and a frequency range of .25 to 10^5 Hz. Data was sampled by a 16 bit A/D converter and stored on magnetic tape. The output of each accelerometer was filtered using a 10th order low pass filter with a cut off frequency of 1 Hz. The resultant acceleration vector was calculated as a function of time given the 3 orthogonal accelerations of the subject and vehicle. A root-mean-square (RMS) value was calculated to represent the amount of acceleration present in each maneuver. For the acceleration and deceleration maneuvers, RMS of the total and longitudinal accelerations were calculated, and for curve data, the lateral and total RMS was determined. The respective uniaxial accelerations were considered the primary accelerations for the maneuvers.

A two-factor ANOVA was performed to determine the effects of position within the vehicle and the speed of the maneuver. Subsequent analysis also considered the effect of sitting in an OEM seat or a wheelchair.

Results/Discussion.

Position in Vehicle: Comparison of the dynamics at different locations within the vehicle showed differences between the rear passenger area and the front of the vehicle. The front passenger and driver areas experienced comparable average RMS accelerations, with the front passenger area averaging 1.4 times the driver area (Table 1). The rear passenger RMS accelerations were the greatest, averaging almost 3 times those of the driver area (Table 1). The effect of position on vehicle dynamics was statistically significant for primary and total accelerations during accelerations and deceleration maneuvers, but not during curve maneuvers (Table 2). During deceleration maneuvers, the effect of the position was dependent on the speed from which the vehicle decelerated. The van pitched during the 20 and 30 mph decelerations, but was not as noticeable during the 10 mph decelerations. As this pitching became more severe at higher speeds, its effects on the linear accelerations present at different locations within the vehicle changed.

The subject exhibited similar accelerations in the front passenger and driver location, except during acceleration maneuvers (Table 1). For these maneuvers the driver showed a total acceleration an order of magnitude higher than the front passenger, even though the longitudinal accelerations were similar. This could be partly because the subject in the front passenger position was sitting passively, while the driver subject was actively controlling the vehicle. In addition to grasping the steering wheel, the active participation in driving could alter the torso accelerations when compared with a subject who is sitting passively.

The subject seated in a wheelchair in the rear passenger area of the vehicle experienced similar RMS accelerations in a wheelchair secured in the driver position (Table 2). The total and lateral RMS accelerations were greater for the rear passenger area during deceleration maneuvers and similar during acceleration maneuvers. During the curve maneuvers, the lateral and total accelerations were less in the rear location than in the driver area.

The results of these comparisons might influence research into driver evaluation. The differences between the dynamics at different positions within the vehicle should be taken into careful consideration when evaluating or studying the stability and function of a driving candidate. While the ideal situation would be to allow the individual to experience the dynamics of the vehicle from the driver's

Table 1: Average g RMS Comparison of Vehicle Positions
Front Passenger vs Driver in Wheelchair & OEM Seat

Maneuver		Vehicle		Subject		Vehicle		Subject	
		Driver in w/c	Rear Pass in w/c	Driver in w/c	Rear Pass in w/c	Driver in OEM	Front Pass in OEM	Driver in OEM	Front Pass in OEM
accel 10	longitud	0.0338	0.0806	0.0291	0.027	0.0338	0.0352	0.0178	0.0227
	total	0.051	0.155	0.0481	0.0427	0.051	0.0375	0.165	0.0226
accel 20	longitud	0.0447	0.129	0.0631	0.0224	0.0447	0.0508	0.021	0.0316
	total	0.157	0.18	0.0879	0.0425	0.157	0.0699	0.187	0.0807
accel 30	longitud	0.0402	0.114	0.0961	0.134	0.0402	0.121	0.0358	0.0299
	total	0.123	0.176	0.143	0.248	0.123	0.26	0.183	0.0438
decel 10	longitud	0.0247	0.117	0.0716	0.0961	0.0247	0.0937	0.0356	0.0488
	total	0.0579	0.167	0.144	0.119	0.0579	0.11	0.0573	0.0677
decel 20	longitud	0.071	0.173	0.203	0.25	0.071	0.107	0.0941	0.113
	total	0.131	0.308	0.265	0.364	0.131	0.161	0.101	0.141
decel 30	longitud	0.12	0.397	0.307	0.358	0.12	0.0973	0.0798	0.156
	total	0.211	0.657	0.428	0.51	0.211	0.183	0.0876	0.194
curve 10	lateral	0.0557	0.0913	0.178	0.082	0.0557	0.0559	0.0343	0.0545
	total	0.0828	0.359	0.326	0.162	0.0828	0.0127	0.0517	0.0851
curve 20	lateral	0.0652	0.201	0.128	0.0308	0.0652	0.0638	0.0527	0.122
	total	0.254	0.382	0.378	0.251	0.254	0.114	0.0742	0.145

location, this might not be appropriate. Similar dynamics of the driver and front passenger areas demonstrate that the abilities of the driving candidate in the front passenger area would be indicative of his/her ability in the driver area. The significantly higher accelerations in the rear passenger area show that performance does not necessarily represent performance in the driving task, but because it is a more severe environment, evaluation of a candidate in this position could be useful in driver training and evaluation.

OEM seat vs. wheelchair: The wheelchair transmitted 2.13 times more longitudinal acceleration than the OEM seat during the acceleration and deceleration maneuvers (Table 4). During the deceleration maneuvers, the wheelchair transmitted 3.7 times more total RMS acceleration, while for accelerations the OEM seat transmitted 2.7 times more total RMS acceleration. During the curve maneuvers, the wheelchair transmitted 4.7 times more total and lateral RMS acceleration. The greater accelerations during deceleration and curve maneuvers makes it a less suitable driving seat than the OEM seat because these maneuvers are typically more unstable than acceleration maneuvers during which the seat back provides support.

Conclusion. This project began to define the complex dynamic environment within a modified van. This environment affects the functional ability of a person with a disability, and a clearer understanding of it will permit better research and clinical practice in evaluating the driving ability of persons with disabilities.

The accelerations experienced by a person in a moving van was found to be dependent on both the position within the vehicle and the seat upon which a person is seated. The OEM seat dampens accelerations and provides a more stable seat. All of the data in this study was taken in the same vehicle. Further research should use vehicles with different modifications to determine the effects of individual modifications on the vehicle dynamics.

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Table 2 **Statistical Analysis** ** significance defined at $p<0.05$

Maneuver	*Primary axis acceleration*	*Total acceleration*
Acceleration	speed effect significant	
	position effect significant	position effect significant
Deceleration	speed x position interaction significant	speed x position interaction significant
Curve	no significant effects	no significant effects

Table 3: Average g RMS Comparison of Wheelchair vs. OEM Seat (Driver Position)

Maneuver		Subject	
		OEM Seat	Wheelchair
accel 10	longitudinal	0.0178	0.0291
	total	0.165	0.0481
accel 20	longitudinal	0.021	0.0631
	total	0.187	0.0879
accel 30	longitudinal	0.0358	0.0961
	total	0.183	0.143
decel 10	longitudinal	0.0356	0.00716
	total	0.0573	0.114
decel 20	longitudinal	0.0941	0.203
	total	0.101	0.265
decel 30	longitudinal	0.0798	0.307
	total	0.0876	0.428
curve 10	lateral	0.0343	0.178
	total	0.0517	0.326
curve 20	lateral	0.0527	0.128
	total	0.0742	0.378

Accelerations experienced by wheelchair users with SCI in a moving van

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Abstract. Wheelchair users who drive must overcome the dynamic vehicle environment to maintain stability. Proper stability might increase function and improve the driving ability of wheelchair users. This project measured the accelerations experienced by individuals with SCI during vehicle maneuvers. The subjects sat both passively and while grasping a structure to simulate gripping driving controls. Seated stability was greater when the subjects grasped the structure. Vehicle and subject responses varied greatly. This result underscores the complexity involved when researching the functional abilities of a SCI population within a complex dynamic environment.

Introduction. Some wheelchair users are unable to transfer into a car and, therefore, must enter a van while seated in a wheelchair. Once in the van, some transfer to a typical van seat, while others drive their vehicles while seated in their wheelchairs. Typically, vans are modified in two ways to accommodate the increased sitting height of a person in a wheelchair, the floor of the van is lowered, a raised roof is added, and a wheelchair lift is mounted to the rear side door. These modifications change the vehicle dynamics by changing such properties as mass, mass distribution, and center of gravity.

Seated stability is compromised by the dynamic driving environment which affects an individual's ability to maintain a stable posture (Kulowski, 1960). While seated in a moving vehicle, the musculature of the trunk, legs, and hips are constantly adjusting to the dynamic environment to maintain an upright posture. For the able-bodied population, this is an unconscious response. For a person with a spinal cord injury, the maintenance of driving posture can become a conscious task.

Posture while driving is stabilized by providing the driver with a large base of support, through use of the seat, backrest, and terminal extremity contacts. Grasping the driving controls closes the links created by the hands gripping the steering control and the shoulder contact with the backrest (Zacharkow, 1988).

Objective. This study positioned persons with cervical level spinal injuries in a wheelchair to measure the dynamic response of the trunk within a moving vehicle. Measurements were taken while the subjects sat passively and while gripping a structure. Accelerations at the sternum and a measure of trunk position was used to relate vehicle maneuvers to trunk accelerations and stability in persons with SCI. The study was designed to be a launching point for an extensive quantification of the driving environment and its effect on the functional ability of a person with a disability.

Instrumentation. The relative position between the subject's trunk and the wheelchair backrest was measured using plate switches. Five switches oriented in a 'T' configuration, a row mounted along the top edge of the upholstery, and two additional switches placed vertically along the spine. A rough measure of trunk position was determined by recording whether a switch was open or closed.

Accelerations were measured with six uniaxial piezobeam accelerometers (range = +/- 5 g; frequency range: 0.25 to 10^5 Hz). The accelerometers were mounted on two tri-axial mounting cubes. Vehicle response was measured by accelerometers mounted on a cube which was secured to the floor of the vehicle and centered between the casters. Subject response was measured by accelerometers mounted on an identical cube secured two to three centimeters inferior to the sterno-clavicular joint of the subject.

Methods. Subjects were four adult drivers and non-drivers with spinal injury levels from C4 to C6. The responses of the subjects were measured with each subject seated in a standard adult manual wheelchair secured to the van using an four-point belt tie-down.

Vehicle maneuvers were performed while the subjects were seated with hands in their laps, and again, while they grasped a structure mounted to the floor in front of the wheelchair. The structure was mounted to the floor in front of the subject and adjusted to allow each subject to grasp it as they would grasp a spinner knob and hand controls.

Acceleration profiles of the vehicle and subject, and general positioning of the subject relative to the seat back were collected while the vehicle performed several maneuvers outlined below:

1. **Acceleration from rest.** Van was accelerated from standstill to speeds of 16.1, 32.2, and 48.3 km/hr (10, 20, and 30 mph) in ten seconds.
2. **Deceleration to rest.** Van was decelerated from speeds of 16.1, 32.2, and 48.3 km/h (10, 20, and 30 miles/hour) to standstill in 4 seconds.
3. **Curve Driving.** Van was driven around a curve at constant speeds of 16.1 and 32.2 km/hr.

Data Collection and Analysis. The output of each accelerometer was filtered using a 10th order low pass filter with a cut off frequency of 1 Hz. The resultant acceleration vector was calculated as a function of time given the 3 orthogonal accelerations of the subject and vehicle. A root-mean-square (RMS) value was calculated to represent the amount of acceleration present in each maneuver.

The effects of the stabilizing structure on the stability of the subjects was expressed by the relationship between the acceleration of the subject and the vehicle. A transmission ratio was defined as the ratio of the RMS acceleration of the subject to the RMS acceleration of the vehicle.

Another estimate of the stabilizing effect of the structure was made using the total time switches were open (T_{OS}) during maneuvers. The duration of each maneuver was calculated. T_{OS} was used to determine the normalized percentage of time switches were open during each maneuver for each subject.

Results. Without the structure, all subjects showed and increase in T_{OS} during deceleration and curve maneuvers (Table 1). An increase in the total RMS subject acceleration yielded a decrease in T_{OS} during acceleration maneuvers and an increase during decelerations and curves.

No significant relationship was found between the total RMS vehicle acceleration and the subject transmission ratio because of the wide variation in vehicle RMS (Table 2).

Discussion. A total of four subjects with spinal cord injury were used in this study, and despite the fact that all are wheelchair users who use or would use a van, the differences in stability and trunk movement were extreme. Two subjects reported using the structure to stabilize their trunks, and the effect of the structure in limiting trunk movement was evident. Research into driver performance should, therefore, use a structure to simulate the closed-link stability normally provided in driving. The functional ability of a person in a

Table 1: Normalized Switch Open Times

Subject	Maneuver	Max Possible T_{OS} (secs)	No Structure % Total T_{OS}	Structure % Total T_{OS}
LM	accel 10	44	41.6	25.7
	accel 20		37	25.7
	accel 30		28	25.7
	decel 10	20	35.3	12.7
	decel 20		73.9	24
	decel 30		89.7	23.8
	curve 10	60	47.8	25
	curve 20	40	71.8	19.1
JF	accel 10	44	0	0
	accel 20		0	0
	accel 30		0	0
	decel 10	20	0.3	0
	decel 20		11.4	0
	decel 30		38.8	0
	curve 10	60	0	0
	curve 20	40	16.8	0
MT	accel 10	44	0.5	0
	accel 20		2.8	2.3
	curve 20	40	14.8	20.8

moving vehicle would be affected if subjects were allowed to stabilize their trunk with their upper extremities. The concern of this study was to define what happens in this environment. Despite the fact that using one's upper extremities for stability might not be proper, it should be taken into account when studying this population.

Studying the accelerations at the sternum of subjects with SCI and the subsequent movement of their trunks, provided a preliminary look at the variations of response to the dynamic environment. Variations in vehicle and subject RMS accelerations, and the variable effect on subject RMS caused by the structure more clearly defines the complexities involved in studying this environment using persons with SCI.

The results can be applied by researchers seeking to simulate the driving environment with a simulator or other vehicle. Using a dynamic environment in a preliminary driving evaluation would allow evaluators to determine if a driving candidate is stable enough to withstand the driving environment, and determine which adaptive driving controls are the most appropriate, without placing the individual behind the wheel of a moving vehicle.

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Table 2: Transfer function data for SCI subjects

Maneuver	Subject	Structure		No Structure	
		Vrms	Srms/Vrms	Vrms	Srms/Vrms
Accel 10	RP	.0763	0.293		
	JF	.24	0.601	.0837	0.351
	LM	.0689	0.608	.216	0.26
	MT	.161	0.81	.126	0.911
Accel 20	RP	.147	0.246		
	LM	.107	0.691	.116	0.559
	JF	.406	0.196	.114	0.621
	MT	.171	0.521	.235	0.595
Accel 30	RP	.125	0.205		
	LM	.125	0.482	.155	0.75
	JF			.251	0.452
	MT			.19	0.926
Decel 10	RP	.072	0.372		
	LM	.0902	2.663	.158	0.799
	JF	.385	0.363	.0978	1.007
Decel 20	RP	.172	0.72	.063	0.381
	LM	.183	0.315	.315	0.608
	JF	.728			
Decel 30	RP	.281	0.72		
	LM	.33	0.457	.144	6.504
	JF	1.47	0.199	.72	0.454
Curve 10	RP	.131	0.305		
	LM	.229	0.338	.133	0.535
	JF	.673	0.188	.673	0.188
Curve 20	RP	.403	0.0958		
	LM	.161	0.586	.268	0.566
	JF	.363	0.646	.71	0.264
	MT	.601	0.219	.389	0.519

ROLLOVER AND DIRECTIONAL STABILITY OF VEHICLES MODIFIED FOR THE PHYSICALLY CHALLENGED

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Abstract

A new dynamic rollover stability criterion for tripped rollover, the minimum lateral impulse, is defined. This criterion and computer simulations of vehicle motion during a rollover accident are used to compare the rollover stability of an original manufactured van with three vans modified to accommodate physically challenged passengers or drivers.

Introduction

Standard manufactured vehicles are often subjected to certain structural changes designed to accommodate physically challenged passengers or drivers. The main objective of the research reported in this paper is to study the effect of such adaptive changes on the rollover stability of the vehicle. Specifically, unmodified, or OEM (Original Equipment Manufacturer) vans, are compared with vans modified as described below:

a) Mod B - the roof of the van is made 13 inches higher and a wheelchair lift is added.
b) Mod C - the floor of the van is lowered 6 inches, its body is lifted 2 inches, and a wheelchair lift is added.
c) Mod D - the floor is lowered 4 inches and a wheelchair lift is added.

There are two types of rollover situations that are of interest; tripped and untripped. A tripped rollover occurs when the vehicle is skidding sideways, and strikes a tripping object such as an obstacle, a curb, soft soil, or other similar terrain feature. The untripped or maneuver- induced rollover results from abrupt maneuvers or excessive driver inputs, such as oversteering, or high speed turning or cornering.

A large majority of single vehicle rollover accidents are classified as tripped rollovers. According to NHTSA's reports, 90 percent of all rollover accidents are single car accidents which occur off the roadway. This implies that most rollover accidents, which are caused by a loss of directional control, are tripped rollovers. Thus, although the parameters involved in a tripped rollover analysis are independent of maneuvering, the roll propensity of a given vehicle is related to its directional or handling stability.

The National Highway Traffic Safety Administration (NHTSA) has proposed three measures of vehicle stability that quantify the roll propensity of a vehicle: the static stability factor (SSF), the tilt table ratio (TTR), and the side pull ratio (SPR). The static stability factor SSF is defined as the ratio of half track width to the vertical height of the center of gravity. The tilt table ratio TTR is measured with the vehicle placed on a platform which is tilted about an axis parallel to the longitudinal axis of the vehicle. Rollover stability is assumed to be characterized by the angle at which the tires on the upper side of the platform begin to lose contact with the platform. The numerical value of the TTR is defined as the tangent of this angle. The side pull ratio SPR is measured by pulling the vehicle in the lateral direction at the height of the center of gravity until the tires on the far side of the vehicle lose contact with the ground. The SPR is defined as the ratio of the lateral force to the weight of the vehicle. These simple static criteria have been applied to both tripped and untripped rollovers.

Dynamic Criteria for Rollover Stability

The SSF, TTR, and SPR are all static criteria. Because the rollover process involves a complex interaction of forces from suspension systems, tires, drivetrains and road surface, dynamic criteria are needed for predicting rollover propensity under dynamic conditions. It is possible to conclude that a vehicle is more stable than another vehicle according to a static metric and find that under certain dynamic conditions the vehicle becomes less stable. This can happen when the frequency content of the lateral forces or accelerations includes some of the natural frequencies of the vehicle. The two existing dynamic criteria for rollover stability are the critical rollover speed and the critical rollover acceleration, which are defined as the least lateral speed and the least lateral acceleration required for rollover. These two criteria are dependent on parameters external to the vehicle, such as the properties of the tripping device in tripped rollover, and, consequently, are not determined only by the structural properties of the vehicle.

This paper introduces a new dynamic criterion called minimum lateral impulse (MLI) for measuring vehicle tripped rollover stability[1]. The MLI criterion uses as a measure of rollover stability the minimum impulse in the lateral direction over the period of time from the start of the rollover process to the instant when the vehicle is just on the verge of overturning. The minimization of this impulse is with respect to all possible time histories of lateral deceleration over the time interval of interest. Thus, the lateral deceleration function for which the lateral impulse assumes its least magnitude while still causing rollover is to be determined. Physically meaningful constraints, such as upper and lower bound bands on the allowable lateral deceleration time histories, can be included in the minimization. The differential equations governing the motion of the vehicle are also treated as constraints. Thus, rollover stability analysis with the MLI criterion is formulated as a constrained optimization problem, which can be solved by mathematical programming methods. The numerical value of the MLI measure is usually given per unit mass of the vehicle so that an equivalent definition of this criterion is the time integral of the lateral acceleration from the onset of rollover to the moment just before the vehicle overturns. Hence, the value of the MLI measure has dimensions of velocity, m/s or ft/sec.

Parametric computer simulation studies can also account for dynamic effects in rollover stability. The Vehicle Dynamic Analysis Nonlinear (VDANL) simulation program[2] is currently being used to study the directional and roll stability of modified vans.

Results

Figure 1 shows a simplified six degree-of-freedom vehicle model. m_s and m_u are the masses of the sprung and unsprung parts of the vehicle and the coordinates y_i, z_i, and Φ_i , $i = u, s$, are the degrees of freedom. This model was used to represent the OEM van and the three modified vans, Mod B, C, and D, in an MLI analysis. Figure 2 shows the deceleration curves that minimize the lateral impulse and the corresponding numerical values of the MLI measure for each of these four vans to reach their rollover angle within 1 second in tripped rollover. The relevant design variables and a comparison of the MLI method to the SSF method is shown in Table 1. The static stability criterion SSF indicates that the most stable van is the OEM van and the least stable van is the Mod B van. According to the dynamic stability criterion MLI, however, the most stable van, for which the lateral impulse required to tip the vehicle over is the greatest, is the Mod B van and the least stable van is the OEM van. The reason for this apparent discrepancy is that the SSF metric depends only on the height of the center of gravity and the track width of the vehicle, while the MLI criterion accounts also for the increase in the sprung mass M_s and, more importantly, for the change in the mass moment of inertia I_{xs}. Table 1 shows that all three modified vans have a greater I_{xs} than the OEM van. Therefore, a greater moment and a greater MLI is required to bring the vehicle to its rollover angle. For the vehicle modifications studied here, the increase in I_{xs} more than offsets the effect of increases in center of gravity height and sprung mass.

Conclusion

The rollover stabilities of an OEM van and three vans modified for use by the physically challenged have been studied. It has been found that, in tripped rollover, the new dynamic criterion MLI for rollover stability predicts different results from those obtained by static criteria.

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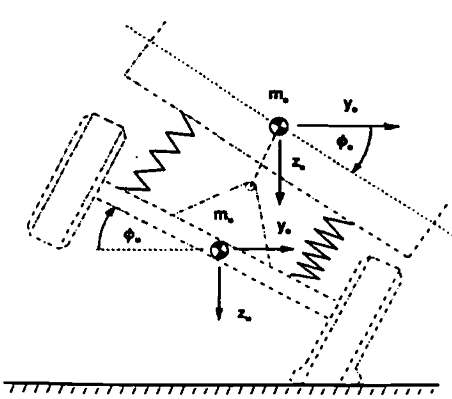

Fig. 1 Vehicle model

Table 1 Inertial Parameters and Rollover Stability Criteria of Four Ford E150 Vans

VAN	M_s (lb-sec²/ft)	C.G. (ft)	I_{ss} (lb-ft-sec²)	SSF	MLI (ft/sec²)
OEM	136.0	2.54	578.8	1.115	11.99
Mod B	148.4	2.72	2144.0	1.042	15.23
Mod C	142.0	2.67	1028.0	1.063	12.82
Mod D	142.0	2.50	878.0	1.100	12.99

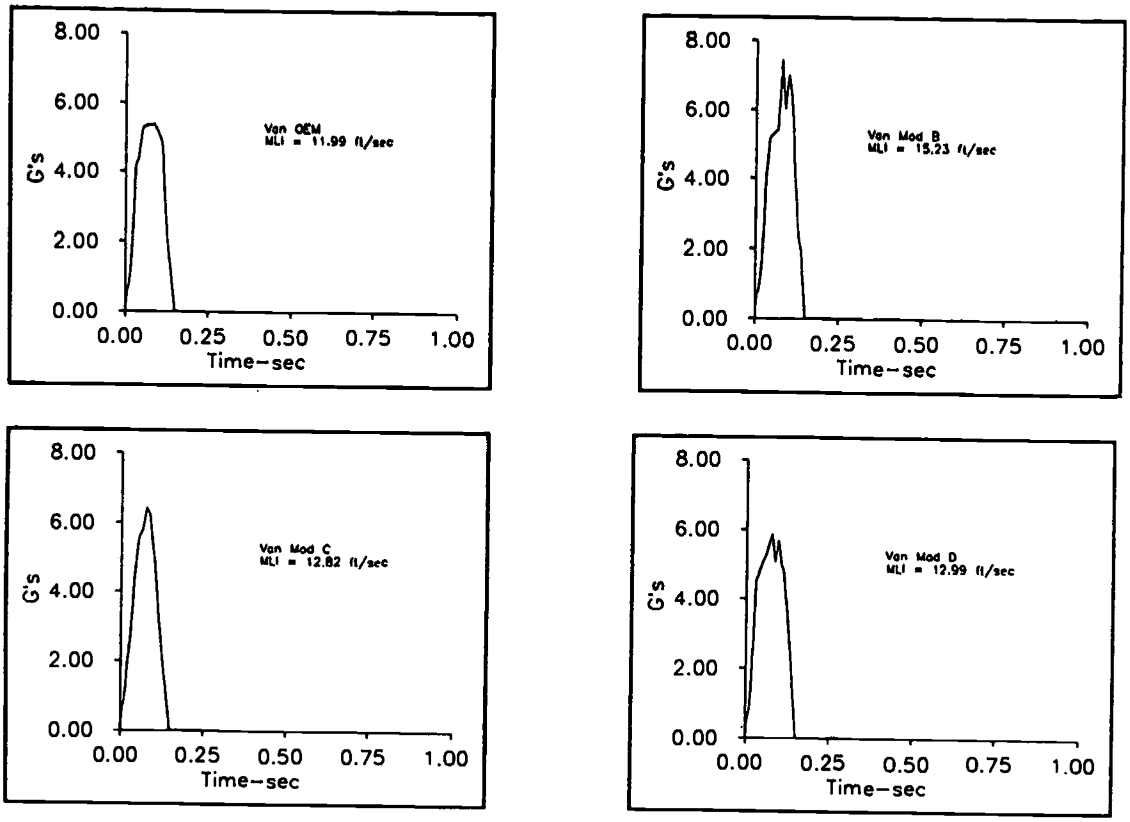

Fig. 2 Minimized deceleration pulses for the four vans

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CRASH RESPONSE OF WHEELCHAIR-OCCUPANT SYSTEMS IN TRANSPORT

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Abstract

A computer model has been developed to simulate the crash effects on a wheelchair-occupant system secured to the floor of a vehicle. The DYNAMAN simulation package has been used to simulate the system that includes a wheelchair surrogate and a Hybrid III dummy. The simulation results agree well with the results of three laboratory sled tests. It has been verified that this model can be used to predict and corroborate sled test results in inter-laboratory tests.

Introduction

The increasing need of mobility for the physically challenged results in a significant driver and passenger population who sit in wheelchairs in vans and buses. The wheelchair tiedowns and occupant restraint systems can reduce the possibility of injury by preventing the wheelchair and occupant from moving and hitting the vehicle interior during a crash. To develop a wheelchair tiedown and occupant restraint system, the dynamic responses (the restraint forces, the accelerations, and the excursions) of the wheelchair-occupant system under crash loadings need to be analyzed. Computer simulations validated by sled tests have been used to study these dynamic responses.

Wheelchair-Occupant Model

A computer model has been developed to simulate a wheelchair-occupant system tied down to a vehicle under the impact loadings of a crash. The surrogate wheelchair model has been developed to simulate a 85kg/187lb powered wheelchair. The occupant model consisted of a 50th percentile Hybrid III dummy. The DYNAMAN (a version of ATB, Articulated Total Body Model) simulation package[1] has been used to simulate the system. Figure 1 shows the surrogate wheelchair on a test sled. The computer model is illustrated in Fig. 2. In this model, the wheelchair mass is lumped at its center of gravity with mass and mass moment of inertia around the three axes. The four wheels are modeled as rigid ellipsoids and connected to the wheelchair body by pin joints. The wheelchair cushion, back, armrests and footrests, and the vehicle floor (or sled platform) are modeled as flexible planes to simulate the contacts between the dummy and the wheelchair, and the wheelchair and the vehicle floor. The dummy is modeled as a series of rigid segments and flexible joints as in standard ATB input files. Each rigid segment has 6 degree-of-freedom. The stiffness, damping (hysteresis and viscosity), permanent deformation, and friction of the contacts between the rigid segments and the flexible planes are determined by given contact functions. The functions can be of arbitrary form, linear or nonlinear. Figure 3 describes the model configuration. The static properties of the safety belt and tiedown (same webbing as the safety belt), were measured and shown in Figure 4.

The sled test runs done at the UVA Automobile Safety Laboratory have been used to tune the model. The main purpose of this tuning process is to estimate unknown parameters such as the hysteresis and viscous damping properties of the contacts between the dummy and the wheelchair.

Figure 5 shows the time histories of rear tiedown and shoulder belt forces. The level of agreement between simulation and sled tests is very good, particularly during the critical loading phase, considering that a comparatively simple model was used to describe a complex physical system. Errors in sled test data also contributed to the difference between simulation and sled test results.

Model Validation

The wheelchair-occupant and tiedown system was used for sled tests in following three laboratories: University of Virginia Automobile Safety Laboratory, University of Michigan Transportation Research Institute (UMTRI), and Middlesex University Road Safety Engineering Laboratory (MURSEL) (UK). The deceleration pulses of these three labs are shown in Fig. 6. The dynamic responses of the wheelchair-occupant system to these pulses are simulated using the model described here, and the results are compared with the test measurements. Table 1 shows the peak values of the restraint forces, accelerations and displacements of the wheelchair and dummy. The correspondence between the simulations and sled tests is very good, although some values, such as the dummy chest vertical acceleration, for the MURSEL pulse show a significant discrepancy. Besides the modeling and measurement errors mentioned above, this discrepancy is also due to the poor repeatability of the MURSEL sled tests.

Conclusions

The wheelchair-occupant model developed in this paper can closely predict sled test results. It can be used to simulate crash responses, and to estimate the effect of parameters such as crash pulse variation, difference in sled platform rigidity, and velocity change variations of sled pulses on output values such as the rear tiedown loads.

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Acknowledgments

This research was sponsored by the National Institute on Disability and Rehabilitation Research (NIDRR).

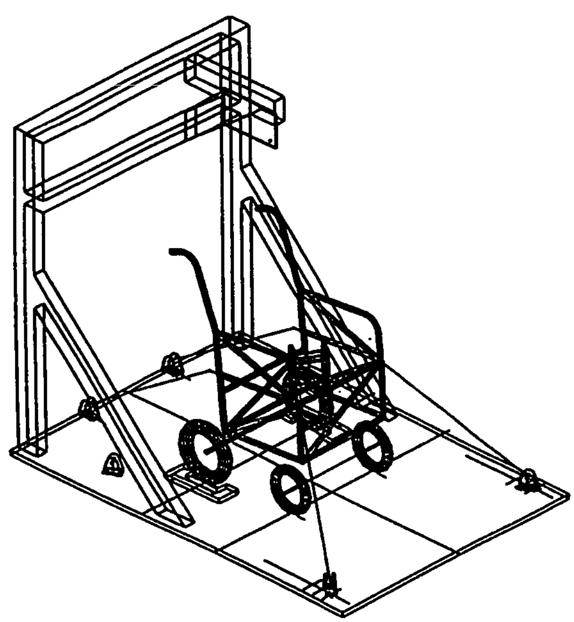

Fig. 1 Wheelchair surrogate on a sled

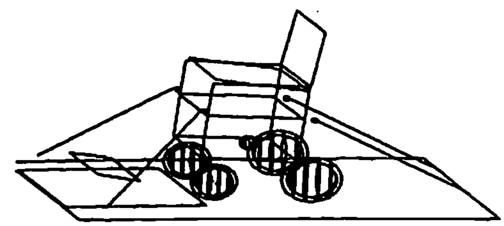

Fig. 2 Wheelchair model

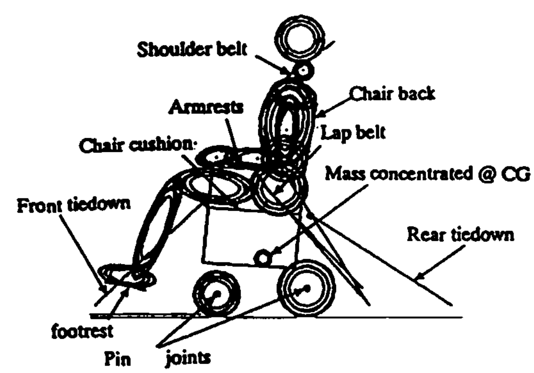

Fig. 3 Wheelchair-Occupant model

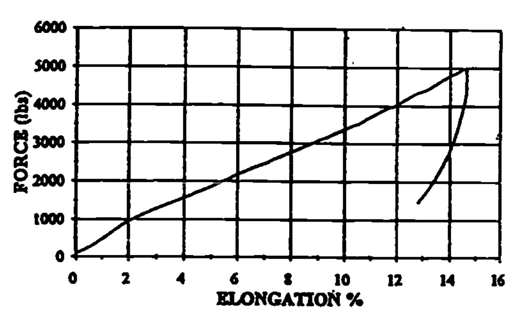

Fig. 4 Webbing force-elongation relation

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Table 1 Comparison of Simulation and Sled Test Results

Peak Values of Parameters	UVA			UMTRI			MURSEL		
	Simulation	Sled Test	Diff. (%)	Simulation	Sled Test	Diff. (%)	Simulation	Sled Test	Diff. (%)
Left Rear Tiedown Force (lb)	4620	4594	0.6	4398	4168	5.5	4109	4238	3.0
Lap Belt Force (left) (lb)	1789	1730	3.4	1823	1747	4.4	1660	1746	4.9
Shoulder Belt Force (lb)	2164	2064	4.8	2107	1885	11.8	2019	1846	9.4
Wheelchair CG Acceleration (g)	31.0	30.7	1.0	31.0	34.8	10.9	31.6	33.0	4.2
Head Resultant Acceleration (g)	62.6	56.3	10.7	63.5	59.6	3.0	56.8	53.7	5.8
Chest Vertical Acceleration (g)	26.2	23.0	10.0	31.0	31.3	11.8	25.0	40.2	37.8
Wheelchair CG Forward Displacement (in)	2.6	3.0	13.3	2.6	n/a	n/a	2.5	n/a	n/a
Head CG Forward Displacement (in)	12.4	13.6	8.8	11.3	12.8	11.7	11.1	n/a	n/a

* All displacements were obtained at the maximum forward moment with respect to the segment position at impact(at t=0).

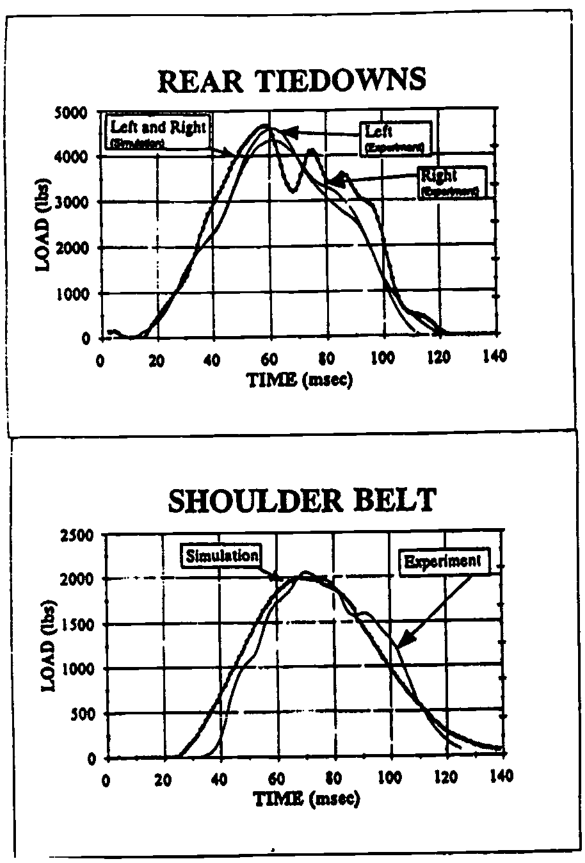

Fig. 5 Rear tiedown and shoulder belt forces. Experimental curves represent the average readings from three UVA sled tests.

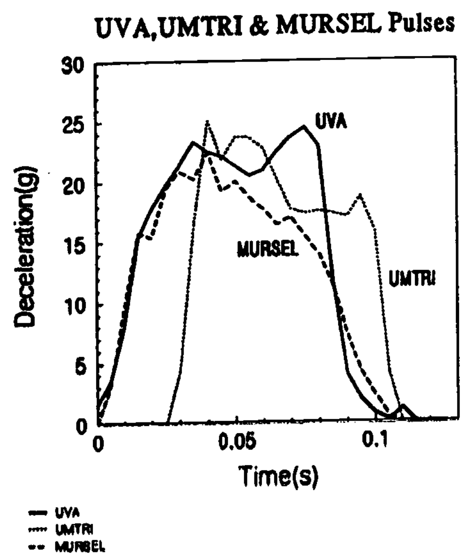

Fig. 6 Sled deceleration pulses

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Wheelchair Tiedown Interlaboratory Test

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ABSTRACT

The development of standards for wheelchair tiedowns and occupant restraint systems for private vans depends on the definition of a dynamic sled test protocol that ensures repeatable results within a given laboratory and reproducible results among various laboratories. A multi-lab comparison study, involving frontal 30 mph sled crash tests of a surrogate wheelchair and 50th percentile anthropomorphic dummy, was conducted in order to determine if the currently proposed test protocol was sufficiently defined. The results suggested that the test protocol achieved a level of precision comparable to that considered acceptable for automotive sled testing.

INTRODUCTION

Although there has been recent federal regulation regarding standards for wheelchair tiedowns and occupant restraint systems (WTORS) for transit and school buses (Americans with Disabilities Act transit regulations [56 FR 45530] and the National Highway Traffic Safety Administration (NHTSA) school bus guidelines), presently there is no standard for privately owned vans. The Society of Automotive Engineers (SAE) Adaptive Devices Committee Wheelchair Restraints Task Group is developing recommended practices which may lead to a national standard for vans. A key element of this task is the development of a dynamic sled test protocol that ensures repeatable results within a given laboratory and reproducible results among various laboratories. This will reduce the possibility that a WTORS which passes the prescribed test at one lab will fail the test at another.

In its current form, the dynamic sled test protocol consists of three major components, the crash pulse, an acceleration / time curve that defines the severity of the crash, the surrogate (test) wheelchair that is representative of an 85 kg / 187 lb powered wheelchair, and the crash dummy that approximates a 67 kg / 165 lb male. Criteria for passing the test is defined by placing limits on the forward movement of the wheelchair and the dummy.

Unlike the surrogate wheelchair and the crash dummy that have been narrowly defined, the crash pulse corridor was drawn to allow for a rather large variation in present crash sled deceleration characteristics. This raised concerns that the potentially large variation in the crash pulse might result in a similarly large variation in WTORS loading and that this variation may cause inconsistent results among laboratories.

A multi-lab comparison test was conducted in order to determine if the proposed test protocol was sufficiently defined to produce reproducible results at different crash laboratories.

MATERIALS AND METHODS

The participating labs, locations for much of the WTORS testing conducted to date, included the University of Michigan Transportation Research Institute (UMTRI), Middlesex University (London), the Canadian Defense and Civil Institute of Engineering Medicine (DCIEM), and the University of Virginia (UVA). The pulse shape of each lab's sled, and the ability to tailor the shape, varied among the facilities. All sled carriages had nominally rigid steel or aluminum platforms and upper shoulder belt anchorage structures.

Development of a Test Protocol

In order to investigate whether parameters that were difficult to specify, such as the crash pulse shape, affected test precision, it was necessary to develop a test protocol that rigorously controlled all other test parameters.

Test hardware

UVA's version of the surrogate wheelchair, developed by Middlesex and the Transport Research Laboratory (TRL), was selected because it had proven sufficiently reliable, provided repeatable results, and approximated the weight of a powered mobility aid (85 kg) (fig. 1). In order to simulate the dynamics of commonly used 4-strap cargo tiedowns, a surrogate WTORS was designed using 7% elongation 48 mm wide polyester webbing. Both the surrogate wheelchair and the WTORS with integral tiedown load cells were shipped from lab to lab. Each lab was responsible for providing a 50th percentile Hybrid II test dummy that was in good repair. Each lab also provided load cells to measure occupant restraint belt tension and accelerometers to record sled carriage, wheelchair, and dummy decelerations.

Crash specification

The collision was defined as it is in the current

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SAE/ISO draft test procedures, namely a 48 +2, -0 km/h frontal impact with the deceleration / time curve within the proposed sled crash pulse corridor (fig. 2).

Test procedures

A comprehensive set of instructions was developed for the participating laboratories. This package included assembly and installation instructions, instrumentation description and calibration information, data collection format, and a test protocol checklist. The test protocol was designed to carefully control the wheelchair and dummy position and WTORS pretension.

Measured outputs

In addition to the loads measured in the four tiedown legs and occupant restraint belts, accelerations were recorded for the sled, the wheelchair, and, multiaxially, for the dummy head and chest. Film analysis was used to determine the forward movement of the approximate chair P point, the intersection of the seat and the back, and the dummy head, hip, and knee.

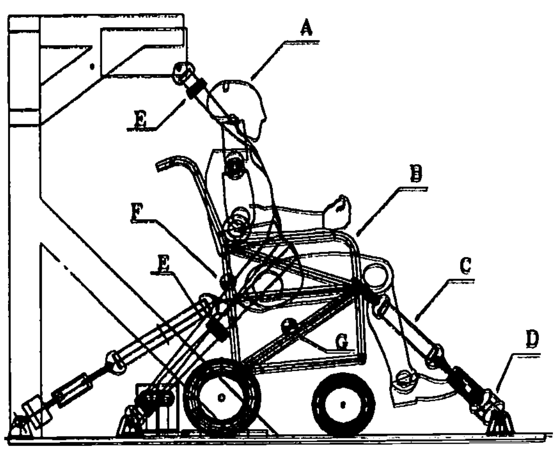

Figure 1. Test hardware including (A) test dummy, (B) surrogate wheelchair, (C) surrogate strap tiedown, (D) integral tiedown load cell, and (E) occupant restraint load cells. (F) locates the approximate wheelchair "P" point; (G) indicates the wheelchair center of gravity.

RESULTS

With some exceptions, the laboratories completed the test protocol without problems and without significant deviation. Preliminary analysis of DCIEM's forthcoming results indicated good agreement with the other labs' data. Table 1 summarizes the test results in terms of peak recorded values.

DATA ANALYSIS

The maximum values of all measured outputs were compared to determine the precision of the test procedures. Precision is defined in terms of the repeatability, a measure of the variability between independent tests obtained within a single laboratory, and reproducibility, a measure of the variability between test results obtained at different labs. Both repeatability and reproducibility are commonly expressed in terms of the coefficient of variation (CV), which is defined as the standard deviation divided by the mean (table 1). Figures 2 and 3 illustrate intra lab repeatability and inter lab reproducibility.

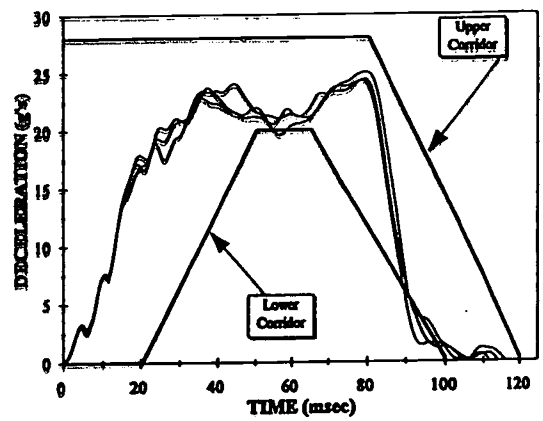

Figure 2. The crash pulse corridor and the three UVA repeatability interlab crash pulses.

A random effects statistical model was used to estimate the results of future tests conducted at another lab. The model uses within and between lab variance to produce a 95% confidence interval for results for future tests using the same inter lab test protocol (table 1).

DISCUSSION

Acceptable repeatability CV's for automotive safety testing usually do not exceed 10%. Standards for test dummy calibration place a maximum limit of 10% for repeatability coefficients of variation (US Code of Federal Regulations, Vol. 49, Part 572). There is general agreement that CV's of 5% are good [Versace 1983, Foster 1977]. Most of the recorded outputs had repeatability CV's of less than 5%; all were less than 10%. This suggests that the precision of the interlab tests for WTORS is comparable to that of state-of-the-art automotive sled testing.

Because the overall repeatability and reproducibility was generally acceptable, the interlab protocol was generally successful in controlling the

PARAMETER	Interlab Average	Repeatability CV %	Reproducibility CV %	95% Lower Bound	95% Upper Bound
Left Rear Tiedown (lbf)	4335	4.1	6.2	3735	4934
Shoulder Belt (lbf)	1932	4.8	7.1	1624	2239
Left Lap Belt (lbf)	1741	4.4	5.1	1657	1825
Sled Accel. (g's)	24.1	1.7	4.6	21.6	26.6
Head result. accel. (g's)	56.5	4.6	6.5	48.5	64.6
Chair x-accel. (g's)	32.8	3.4	6.7	27.8	37.9
Chair p-pt excursion (in)	2.1	9.5	14	1.3	2.8
Head excursion (in)	13.7	5.5	12	9.9	17.3
Hip excursion (in)	6.0	3.3	12	4.4	7.6

Table 1. Average peak values, repeatability and reproducibility CV's, and 95% predicted confidence intervals for future test results.

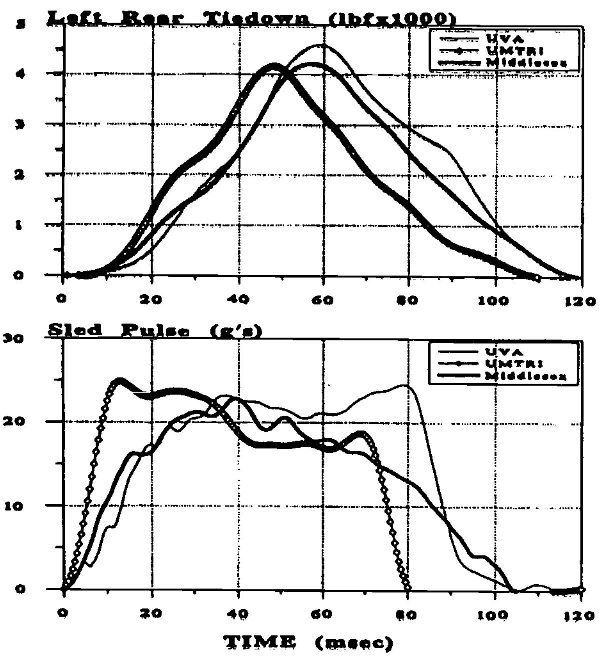

Figure 3. Interlab Reproducibility. Each curve is the average of the labs' 3 replicate tests.

identified sources of variability. The three observed variations in sled crash pulse shape and in sled platform rigidity seemed to have little effect on the test results. This finding, along with the relatively limited predicted confidence intervals, suggests that a standard test protocol can be written that should minimize the possibility for a WTORS to pass the test at one facility while failing at another.

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ACKNOWLEDGMENTS

Members of the SAE Adaptive Devices Committee Wheelchair Restraints Task Group and the International Standards Association (ISO) WG-6 provided assistance in designing the test. Laurin Garland, TES Limited, coordinated the testing at DCIEM. John Aitchinson, UVA Department of Mathematics, developed the random effects model. This research was sponsored in part by the National Institute for Disability and Rehabilitation Research (NIDRR) and the Commonwealth of Virginia Center for Innovative Technology.

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GUIDELINES FOR WHEELCHAIR SECUREMENT AND PERSONAL RESTRAINT

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Abstract

Significant efforts have been made to improve the safety of wheelchair users while traveling in motor vehicles. There remain, however, many difficulties when the present wheelchair securement and personal restraint systems are used in public transit. A set of guidelines was formulated through consensus development of industry, research, and wheelchair using individuals that identifies the needs of all groups involved with the public transportation of individuals in wheelchairs. The guidelines address operation and performance characteristics of securement and restraint systems that will be acceptable and widely used. A test protocol to assure feasibility of the guidelines is also described.

Background

Much work has been done in recent years to evaluate the crash safety of wheelchair securement and personal restraint systems (1,2,3). These efforts provided a better understanding of how crash worthiness principles can be applied to wheelchair transportation to enhance the safety of all passengers. Standards and legislation have utilized the results from this work to identify aspects of wheelchair securement and personal restraint system that offer a high level of protection.

The implementation of wheelchair securement and personal restraint technology on public transit vehicles, however, has encountered numerous operational difficulties that interfere with their proper use (4,5). Developing acceptable securement and restraint systems for public transit is particularly difficult because the needs of many diverse groups must be considered. To address this problem, the Transportation Research Board has brought together these groups to reach a consensus on the needs for securement and restraint systems that are acceptable for public transportation.

Objective

These guidelines provide outcome measures to be used for the development of wheelchair securement and personal restraint systems that are compatible with public transit. The guidelines will also be useful to transit systems to assist in the selection of securement and restraint systems. The validity of the guidelines will be demonstrated through testing of model securement and restraint systems.

Approach

The issues present in public tranportation that make successful wheelchair securement and personal restraint particularly difficult are listed in Table 1.

Table 1. Public transit issues

Widely varying wheelchairs
Widely varying individuals
Varying vehicles designs
Varying locations of wheelchair user
Operator/wheelchair user interface
Securement time
Concerns of other passengers

A resource panel was established consisting of recognized leaders from wheelchair users, transit providers, and manufacturers of wheelchairs, vehicles, and restraint systems. The diversity of the panel members assured that the needs of each group were considered in the guidelines. Each panel member provided expertise in a specialty area of securement and restraint.

The guidelines that resulted from this effort provide outcome measures for performance and operation characteristics that are needed for acceptance in a public transit environment. The primary sections of the guidelines are given in Table 2.

A model securement and restraint system will be developed and tested for conformance to the guidelines. The guidelines may be modified, with

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approval of the resource panel and the TCRP project panel, to assure that all the recommendations can be achieved in practice.

Table 2. Securement and Restraint Guidelines

Performance	Operation
Driving	Information
Impact	Ergonomics
	Securement Time
	Feedback
	User Dignity
	Effect on Passengers
	Reliability

Results

Performance Guidelines

The guidelines suggest that wheelchair securement and personal restraint systems should perform adequately under normal driving and impact conditions. The conditions to be evaluated are given in table 3.

Specific test procedures are defined to evaluate the performance of securement and restraint systems. For each test, the wheelchair should be secured to a simulated vehicle floor, and a test dummy restrained in the wheelchair. For driving conditions testing, the guidelines suggest simulating the driving maneuvers through the use of either a tilt table or pull tester. Impact testing should be performed using a sled impact tester. Laboratory methods are recommended because they are more convenient, less expensive, and more reproducible than testing with a vehicle on a test course.

Table 3. Performance Test Conditions

Driving	Impact
Max. Straight Accel.	20 g. Frontal
Max. Straight Brake	5 g. Rear
Double Lane Change	5 g. lateral
Right Turn	
Left Turn	

The parameters to be evaluated during the testing are given in table 4. Both tests measure the response of the test dummy to predict the response of an individual in a wheelchair. The driving test evaluates comfort and the impact test evaluates the potential for injury.

Table 4. Performance Test Parameters

Driving	Impact
Wheelchair Displ.	Wheelchair Displ.
Test Dummy Displ.	Test Dummy Displ.
Test Dummy Accel.	Test Dummy Injury
Wheelchair Tipping	
Dummy/Bus Contact	

Operation Guidelines

The section of the guidelines that looks at operation issues deals with the aspects of securement and restraint systems that enable them to be accepted for use in a public transit environment. It is important that the individual in the wheelchair and any individual who may be assisting with the securement or restraint process, be able to use the system correctly and quickly.

Adequate information is the first step toward the efficient use of a securement and restraint system. The guidelines recommend that information be provided through brochures, manuals, training sessions, and on-board instructions.

The securement and restraint system should operate easily to reduce securement time, prevent occupational injury, and encourage user independence. The guidelines identify easily accessible locations for system components that require handling, and maximum forces to operate the system.

For the safety of all passengers on the vehicle, the wheelchair must be adequately secured. The securement system should have a feedback mechanism to notify the vehicle operator when the wheelchair securement is complete.

The guidelines recommend that a securement system should be able to be attached to most wheelchairs within sixty seconds. They also recognize that the securement system should be able to be released in less than fifteen seconds in an emergency. A redundant release should be included to release the wheelchair from the securement system if the normal release mechanism malfunctions.

The guidelines further suggest that securement and restraint systems be designed to minimize the contact between an individual who is assisting with the securement and restraint and the individual in the wheelchair. It is indicated that this can be encouraged by locating the parts that require handling in the ergonomic locations identified in the guidelines.

It is important that the activities of the other passengers be minimally affected by the presence and use of a securement and restraint system. The guidelines specifically recommend attention to preventing hazards and interference with the seating or movement of other individuals on the vehicle.

Well maintained and functioning securement and restraint systems are vitally important to the safety of all individuals on the vehicle. The reliability of these systems is addressed in terms of maintenance, tamper resistance, and durability against aging, wear, and the elements.

Discussion

When evaluating the performance of securement and restraint systems, it is desired to predict the response of the wheelchair users to indicate a level of comfort and injury protection. The approach suggested here is to identify threshold levels of motion and forces of key anatomical locations that can be clinically associated with comfort and injury tolerance. Instrumented test dummies then provide test data for comparison to these threshold levels.

The ability to accurately predict motions and forces applied to wheelchair users based on the response of test dummies, however, is a significant concern. The use of test dummies is suggested here to provide a reproducible test methodology that can be used to compare the performance of securement and restraint systems. The correlation between the test dummy response and that of wheelchair users is an area that needs additional research.

There is little data available on the real life success of the current securement and restraint systems in life-threatening accidents. Test data indicates that if the systems are applied correctly, they will be highly effective. A securement and restraint system is only effective protection, however, when it is used correctly. All of the factors presented here must be considered when systems are designed and selected so that their correct use does not conflict with the other demands in a public transit environment.

Many of the issues that are addressed in these guidelines are not identified in other standards, guidelines, and legislation, but they are critical issues to consider if wheelchair travelers are to be efficiently accommodated in public transit.

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Acknowledgments

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CAR ADAPTATIONS FOR PEOPLE WITH SPECIAL NEEDS IN EUROPE A SIMULATOR STUDY EVALUATION

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ABSTRACT

Adapted cars are used to enhance the independent mobility of People with Special Needs (PSN). ATT systems are designed to increase comfort and safety of able-bodied drivers. The requirements of Drivers with Special Needs (DSN) are mostly not included in the design of these systems. The influence of ATT systems on workload and driving performance of DSN in adapted cars should be tested as well. Driving simulator experiments were performed to obtain a baseline for testing ATT systems in future.

BACKGROUND

Independent mobility is an important factor which influences the quality of life of People with Special Needs (PSN). One way to improve independent mobility for people with impairments is the use of adapted cars. More and more Advanced Transport Telematic (ATT) systems, like automatic distance keeping and intelligent cruise control, are developed to make driving a standard car comfortable and safe. Basic MMI (Man Machine Interaction) design of new cars is often based solely on the requirements of able-bodied drivers, while DSN (Drivers with Special Needs) are normally not considered. Adaptation requirements and the technical realization relies on skilled craftmanship, to suit individual DSN with specific needs. A gap exists between the resources and market size of standard car industries and of the car-adaptation industries. In an effort to bridge this gap the aim of the TELAID (Telematic Applications for the Integration of Drivers with Special Needs) project has been to describe the requirements of Drivers with Special Needs (DSN) on the one hand (1) and investigate the usability of telematic applications in facilitating driving for DSN on the other hand. Integration of telematic applications could decrease the drivers workload and facilitate driving by PSN who are not able to drive yet. Design guidelines for the MMI interface of telematic applications, taking into account the requirements of DSN, are essential.
The aim of the first phase simulator experiments, described here, was to find the baseline performance of car-adaptations currently used by DSN. Driving performance has been subject to research before. Yet little research has been done to investigate the influence of car-adaptations on the driving performance and workload of DSN.

RESEARCH QUESTIONS

The intention of this study was to analyze wether specific control aids conform to the specific needs of a group of DSN and not to assess wether certain impairment groups should be restricted or not be permitted to drive. The main research question was to which extend the use of car-adaptations, especially hand controls, influences the performance and workload of DSN.
The following hypotheses were formulated:

1. It is expected that there is a difference between DSN using a hand controlled brake and accelerator and able bodied drivers using pedal control in the reaction to emergency situations (brake reaction time).
2. It is expected that the general (overall) driving performance is the same for the able-bodied drivers and DSN. For certain components of the driving task differences are expected.
3. It is expected that DSN using full manual control experience a higher mental and physical workload compared to able-bodied drivers using conventional pedals.
4. It is expected that there are differences in the reaction to emergency situations, the performance of the driving task and mental and physical workload due to the type of full manual control used.

The simulator experiments were performed at the Swedish Road and Traffic Research Laboratories (VTI) (2) and at the TNO Institute of Human Sciences, (IZF) (3) in the Netherlands. The chosen research methods were similar. At VTI a moving base driving simulator was used and at TNO/IZF a fixed base driving simulator. Method and results from the Dutch experiments will be discussed here.

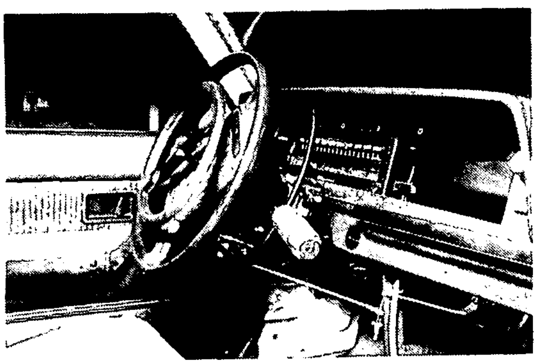
METHOD

The design of the experiments was a classical single factor design with an experimental and a control group.

Subjects

Testing all categories of drivers with special needs was not possible within the time and resource limits of the project. Subjects were selected from the largest category

of DSN using car adaptations, people with a lower limb impairment. From the requirements inventory of people with special needs (1) it became clear that the visual impairment group as well as the lower and upper impairment groups presented relatively large problem areas. The vision capabilities of car-simulators are somewhat limited, which is another indication for the choice of mobility impaired subjects. The IZF target group consisted of experienced paraplegic drivers. The manual controls used were similar to the ones the DSN use in daily practice.
Thirty subjects participated in the Dutch study. Ten subjects were used to drive with a segmented grip hand-controlled accelerator under the steering wheel, ten subjects used a ring accelerator above the steering wheel. Both experimental groups used the same hand controlled brake.



The control group consisted of able bodied drivers using pedal control of accelerator and brake.

Driving task
A three level - strategic, manoeuvre and control - driving task definition (4) was extended for DSN, to include additional tasks like access (entering and leaving the car) and car maintenance (1). The driving task for the simulator study was composed of components from control (steering, braking etc.) and manoeuvre (traffic interaction) level (5).

The experimental road consisted of a two lane 80 km/h road of 80 km long, 7.2 m wide, which is common in the Netherlands. It included sections with many curves and sections with few curves with oncoming cars and cars parked in the driving direction. Some of the parked cars started to merge. Red and yellow squares appearing just above the horizon were used to test emergency braking. Subjects were instructed to brake as fast as possible to the red squares and ignore the yellow ones.

All subjects performed the same driving task. A practice route that was driven before the experimental route had similar characteristics, but no merging cars.

Measurement methods
Driving performance was evaluated comparing brake reaction times and comparing the mean and variation of the speed and of the lateral position of the road under six different driving situations.
Physical Discomfort in the upper body area, especially the hands was measured using an adapted version of the LMD scale introduced by Van der Grinten (6). On the LMD scale subjects indicated a physical discomfort level before and after the experiment.
Subjects had to rate *workload* aspects, mental demand, physical demand, time pressure, performance, effort and frustration, using the Raw Task Load Index (RTLX) (7). The RTLX was filled out for the driving task as a whole and for six more specific situations.
Subjects filled out two questionaires, one before the experiment on driving experience and age and one after the experiment on the comparability of the simulator driving to driving their own car.
Since most DSN came to the simulator in their own car it was possible to compare the control forces required for accelerating and braking in the simulator to the forces required for accelerating and braking their own car.

RESULTS
Minor differences, significance ($p<0.05$), were found in the *driving performance*: The ring accelerator group showed a larger standard deviation of speed during straight sections and the driving of sharp curves and also a larger standard deviation at the steering wheel position and increased nr of braking actions during the overtaking of parked cars.
The LMD scale showed a clear *physical discomfort* increase for the group using the segment accelerator in the fingers of the right hand.
No differences in *workload* (RTLX) were found between the groups.
An overview of the *control forces* [N] for both experimental groups is given in the following table:

	group	accelerator		brake	
		minimal stroke	full stroke	minimal stroke	full stroke
mock up	segment	10	20	20	45
	ring ac.	10	25	20	45
own car	segment	23 ± 12	45 ± 17	14 ± 7	40 ± 14
	ring ac.	19 ± 12	39 ± 13	18 ± 11	37 ± 15

Although there is no absolute norm for safe driving, from an overall view of driving performance in the simulator tests, we subjectively estimate that differences found in this study are within the safety limits.

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DISCUSSION

The experiment was carried out to evaluate the merits of commonly used adaptations for paraplegic drivers. The method presented here has proven to be useful. Experienced DSN (mobility impaired), with well designed adaptations for the primary control of their car perform very much the same as able-bodied drivers driving standard cars. Though there seem to be indications that they do it at a higher cost. Differences in performance could be partly traced back to the way the car was adapted with the ring accelerator. A proper design and installation of hand controls combined with a car with low level pedal forces can contribute to decrease the level of discomfort and fatigue on long driving distances.

The reported study forms a necessary baseline for further simulator studies regarding driving performance of DSN. Introduction of Advanced Transport Telematics in private cars can in a crucial way enhance mobility for DSN but it might as well ruin what has already been gained. This would be the case if the ATT systems do not correspond to the needs and abilities of people with special needs. Adaptation for DSN is often based on ad hoc principles and very seldom any evaluation of the system (driver + adapted car) is carried out. The use of adequate and common assesment methods, design guidelines and legislation could facilitate an optimal use of ATT systems and establish safety requirements. A natural step on the way to develop assessment methods would be to continue the simulator studies by introducing ATT systems. The selection of these systems could be based on two principles:

1. How could ATT systems enhance driving performance or comfort for DSN,
2. How do different interaction modalities due to the introduction of ATT influence driving performance of DSN.

Finding a way to incorporate DSN requirements into the design of standard ATT components could resolve the indicated gap and should be strived for. This principle is valid for many rehabilitation fields as was mentioned before by Vanderheiden (8).

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A SMALL SCALE DRIVER EVALUATION VEHICLE

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Abstract

To provide an intermediate level driver evaluation vehicle, a golf cart based small scale vehicle has been built. This Small Scale Vehicle (SSV) contains extensive safety features to protect the client and the instructor. The instructor can obtain full control of the vehicle at any time. Broad testing capabilities verify the client's performance. The design required a vehicle for use with stroke, spinal cord, and traumatic brain injury patients. An adaptive steering wheel, hand controls, and left accelerator pedal allow a wide range of patients to use this device. The equipment has been built and is in use. Currently we are gathering data on patient and equipment performance to use as a data base for future patient comparisons.

Problem Definition

As patients adapt to selected injuries, there is often a need to evaluate their driving skills, with training or retraining as appropriate. Because of the wide variability and unknown responsiveness of patients to highway driving, it was decided that a safer environment was necessary than a highway activity provides. Certain classes of patients, such as the brain injured, might exhibit acceptable behavior in the classroom, but not be able to perform in a moving vehicle. Some kind of actual driving was deemed necessary, yet controlled conditions were equally important.

In an effort to provide this opportunity, a small scale driver evaluation vehicle was developed. Aside from allowing basic driver evaluation, modifications make measurement of certain responses under safe driving conditions possible. Safety of the patient was of utmost concern in the design of the vehicle. Also, since vehicles with zero effort systems are nearby[1] it was decided to concentrate on a vehicle which would meet the needs of most of our clients. The desired vehicle would also fill the gap between our road vehicles and the classroom based testing equipment. It would be adaptable to a wide range of tests, adapt to different types of physical needs, and drive over grass.

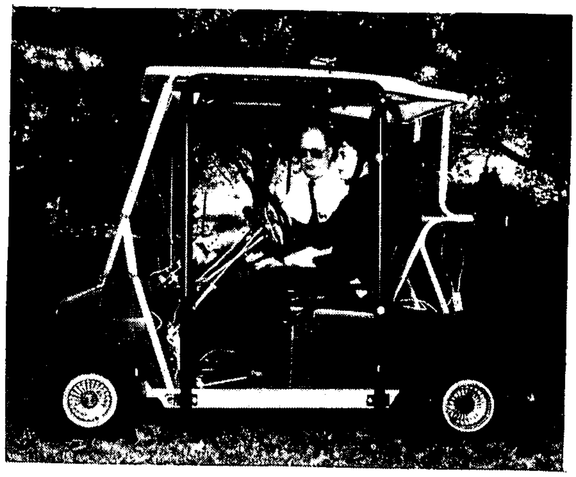
Rational Design

Safety and functional testing guided the vehicle design. As a platform, the Club Car golf cart powered by a 36 volt DC motor was chosen. The safety goals included bucket seats for patient support, automotive style lap and shoulder belts, amber flashing light on roof, electrical interlock so that vehicle could not be started without an instructor, windshield for protection, rear view mirrors for training and evaluation, steel cage around occupants, headlight, brake lights, and turn signals.

The functional evaluation equipment included adjustable hand controls (braking and acceleration), adjustable position steering wheel with an assortment of hand attachments, a left foot accelerator, an instructor's brake, hand parking brake, reaction timer with various conditions, instructor timer control, random timer control, instructor selected stop light pattern, left turn avoidance test, manual control of stop lights, and a remotely operated stoplight. The instructor controlled events can be initiated without informing the client.

Development

The items in the rational design were integrated into the structure of the basic golf cart to produce the functional unit illustrated below. Instructor controlled parameters are divided between a control panel on the right front of the unit and an instructor held pendant. The control panel is shown below. The upper left of the panel contains the main power controls, amber light switch, and a circuit breaker to protect the instrumentation. The digital timer readout is in the upper right. The lower half of the panel contains switches which set up the test conditions. One switch determines whether the instructor can delay this event until the driving conditions are appropriate. The next switch determines whether a combination of the four cart mounted stop lights are used or whether a remote



stoplight is used. There is a timer enable switch. There are two different tests for response of the patient. The patient can respond by stepping on the brake or by executing a sharp left turn avoidance manoeuver. The Test Brake/Turn Switch sets up these conditions. A signal Manual/Timer Switch selects either the timer or the operator initiated activity from the hidden hand-held pendant. A timer reset button permits resetting the timer after use. The seat safety switch can be set to require a person in the right seat before the vehicle will move. This will prevent an over-eager student from making the vehicle move before the instructor is in place. There is also a safety switch in the driver's seat so that the vehicle can not be made to move if there isn't a person in this seat.

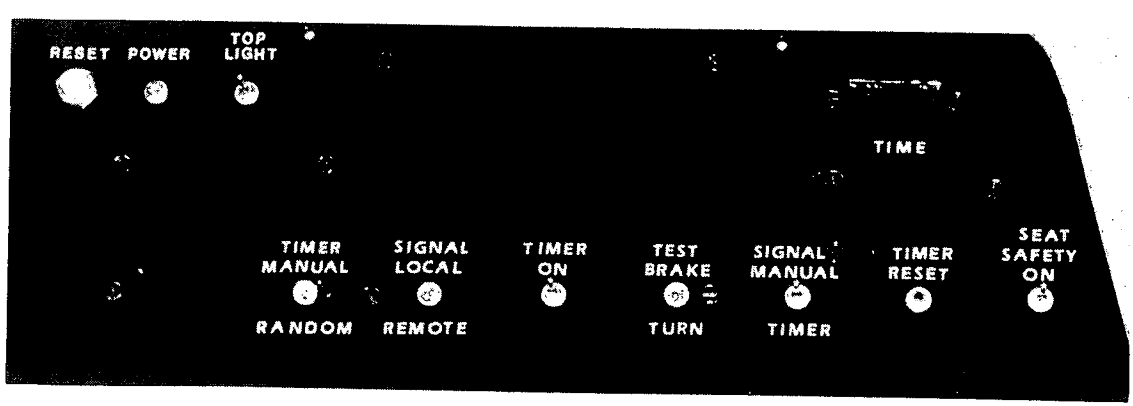
The pendant was designed so that it was quiet in operation and could be held on the right side of the instructor out of the client's view. The pendant contains four lever switches and one push button switch. The push button switch activates the signal lights in the manual mode and the timer sequencer in the timer mode.

Four red signal lights are located on the SSV. Each 11 mm diameter light is mounted in a 5.5 cm by 8.4 cm by 3.8 cm box which has two suction cups attached to it. The selection of these lights is controlled by the instructors pendant. The suction cups allow positioning of the lights at various locations on the windshield and on a clear plastic piece across the back of the vehicle. The rear lights can be positioned to be in the patient's field-of-vision when looking in the rear-view mirror. The lights can be used to evaluate the patient's visual perceptual ability under actual conditions.

The hand controls are Supergrade IV by Handicaps, Inc. A left foot accelerator is also from Handicaps, Inc. An assortment of quick release spinners by Greshman Driving Aids, Inc. is available for the client's use. The adjustable steering column was manufactured to our specifications by Drive Master. The electronic timer is the standard AAA Automatic Brake Reaction Timer. This timer was modified to work on 12 volt DC.

<u>Evaluation</u>

The vehicle has been in use for over a year. Over 25 spinal cord, stroke, and traumatic brain injury clients have used the vehicle in various types of training activities. The adaptability has been verified by the variety of patients who have used the vehicle. An instruction manual has been written for reference by the staff. It takes approximately one hour of instruction for a therapist skilled in



driver training to be able to use the vehicle to evaluate a patient. One class of patients that this vehicle is particularly suited to is the young spinal cord injury patient who has never driven. This vehicle provides a safe environment in which basic skills can be learned. Patients and therapists like the ease of entry, the bucket seats, safety belts, and the general feeling of security provided by a small, slow, vehicle which is operated off of the roadway.

Discussion

The development and use of a small scale driver evaluation vehicle has been presented. This vehicle meets the needs of our patients at an appropriate technology level. The SSV fills an important niche in the range of available devices. Clients feel safe in this device and are not afraid and apprehensive as they might be in a full-sized vehicle. The excellent visibility and feeling of safety make the SSV fun to drive. The characteristics of the SSV permit tests which could not be safely performed with a full-sized vehicle. The SSV also gives the instructor the opportunity to experiment with different control settings in a safe environment.

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A HUMAN POWERED VEHICLE FOR THE PHYSICALLY DISABLED

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ABSTRACT

A unique, three wheeled, human powered vehicle (HPV) was designed and constructed for an eight year old boy with spina bifida. The design allows the boy, Kramer, to propel the tricycle using a reciprocating motion. This simple motion is one that Kramer can accomplish, in contrast to the more complex rotating motion used in conventional tricycles and bicycles.

The tricycle also has specially designed pedals to hold Kramer's feet. A five speed internally geared hub provides a low gear for climbing hills as well as high gears for higher speeds. This HPV is the first of several tricycles that Kramer has been able to ride, providing him with fun, exercise, responsibility, and independence.

BACKGROUND

The recipient of the tricycle, Kramer, is an active eight-year-old boy with spina bifida. Kramer has no feeling in his feet, and he wears braces to keep his feet aligned forward. Kramer can walk and run for short distances, although he tires easily, since some of the muscle groups in his legs are underdeveloped, especially the hamstring muscles on the back of the thigh. As a result, Kramer has difficulty keeping up with other children his age. Also, despite repeated attempts, Kramer appears to lack the coordination to perform the rotating leg motion required to propel a conventional bicycle or tricycle.

Kramer's parents have previously purchased a number of tricycles, including a very expensive device custom-built for Kramer. In all cases these machines have proven to be ineffective, as they all had pedals that required rotating motion. Also, Kramer had difficulties keeping his feet positioned on the pedals. Kramer's attempts at fun and exercise frequently ended in frustration as a result of these problems.

After meetings with Kramer and his parents, and observing Kramer attempt to ride his older tricycle, several design objectives became apparent. The new HPV would require a totally different pedaling mechanism so that Kramer could propel the vehicle; one that did not depend on rotating motion. The design team's testing of Kramer showed he is particularly strong in leg extension, especially when he can push against a back support. The drive mechanism for the prototype should take advantage of this. Foot supports to keep Kramer's feet on the pedals were also important.

STATEMENT OF THE PROBLEM

The freedom and responsibility offered by a tricycle or bicycle is an important part of the development of many children. The design team's goal was to design, construct, and evaluate a device that would not only provide Kramer with exercise and habilitation, but also freedom and responsibility.

As discussed above, foot support and the use of leg extension were significant concerns. Several other important overall goals were also considered throughout the design process. Safety was of course a primary concern. Also, the vehicle was to be as lightweight and portable as possible. Another significant concern was to ensure that Kramer would not quickly outgrow the tricycle. Thus, adjustability of the seat and pedals were addressed. When possible, off the shelf parts were used to help minimize repair and machining costs. Finally, it was important to make the vehicle fun. For Kramer, fun was synonymous with fast. The designers tried hard to make the vehicle look "cool", like a different bicycle instead of a rehabilitation device for the disabled.

DESIGN AND DEVELOPMENT

A team of five senior mechanical engineering students designed and built the HPV according to the objectives described above. Detailed results are contained in [1].

After consideration of numerous mechanism concepts, a design using reciprocating pedals was chosen for use in the HPV. The final concept is shown schematically in Figure 1.

Force is applied to the pedal and transmitted down the crank arm to the cable crank. The force is then transmitted along the cable and into the one way clutch mechanism. The clutch locks in the forward direction, and free-wheels in the reverse direction. When pressure is released from the pedal, a return spring pulls the pedal back to its forward position. A schematic showing the overall drive mechanism is shown in Figure 2.

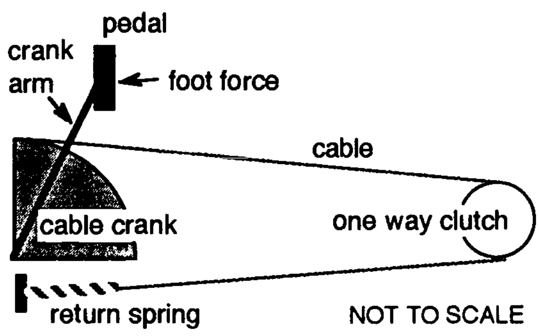

Figure 1 - Schematic of the pedaling mechanism

The force exerted on the pedals is transferred into two one way clutches as previously described. Force is then transferred via a chain into the five-speed internally geared hub. This hub features a single lever, indexed shifting with the shifter located conveniently on the handle bars of the tricycle. From the five speed hub, force is transmitted through the drive chain to the rear axle by means of a keyed gear. An important feature of the mechanism is that the two pedals are not linked together. One pedal can be pushed down while the other is up, or both can be pushed at the same time.

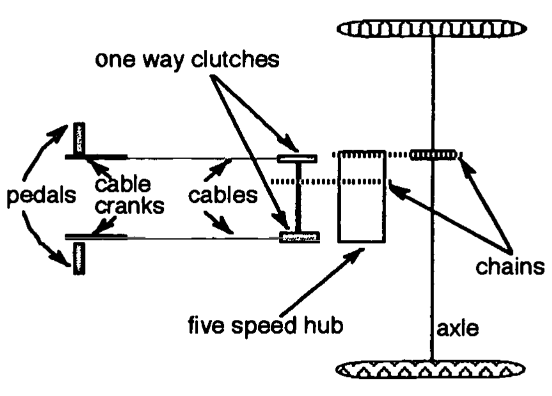

Figure 2 - Overall schematic of the drive mechanism

Using the mechanism described, a preliminary test model was constructed by modifying an industrial grade (adult's) tricycle. The test model proved, most importantly, that the proposed mechanism worked. Kramer could not only ride the test model, but thoroughly enjoyed riding it, even though it was extremely heavy and ungainly. The team observed Kramer extensively while he rode the test model, both on a parking lot and indoors on a modified set of bicycle "rollers". These observations were critical in modifying the design for the final prototype tricycle that was delivered to Kramer. From the test model, it was determined that Kramer could exert a greater force on the pedal at the end of the stroke than at the beginning. Thus, the configuration of the cable crank was changed from a constant radius to an increasing radius, giving Kramer a greater mechanical advantage (higher torque) at the beginning of the stroke.

Also, the ideal design, placement, and travel of the pedals were determined using the test model. The pedals themselves were developed not only to secure Kramer's unfeeling feet against slipping, but also to allow him to get his feet in and out of the pedals quickly and safely without assistance. The pedals consist of off-the-shelf bicycle pedals with inexpensive molded plastic guides attached to them to accomplish the above goals (the guides are not shown in Figures 1 and 2). Seat position, location of the handlebars, crank arm length, pedal placement, and head (steering) tube location were also established using the test model.

With the information and measurements gathered from the test model, a prototype tricycle was manufactured. The prototype can be described as a recumbent tricycle with a reciprocating crank mechanism. The frame was constructed from 1.25 in. outside diameter 4130 Cr-Mo steel tubing. The tricycle features 20 in. aluminum alloy rims on all three wheels, a five speed internally geared hub, and a single drum brake on the front wheel. The completed prototype tricycle is shown in Figure 3.

EVALUATION

Much of the testing occurred during the design and development phase of the project with the test model. The prototype tricycle was initially tested with Kramer riding it in an indoor hallway. The tricycle worked well, and was shortly thereafter delivered to Kramer for use at home. Kramer instinctively pushes the pedals with both feet together when starting from a stop. This gives way to alternate-foot pedaling as he speeds up. (He was not trained in this pedaling technique - it just seems to happen naturally.) As with most children, steering and braking required a little practice for Kramer to master. Early on, he "field tested" his tricycle with several harmless collisions with curbs and other stationary objects.

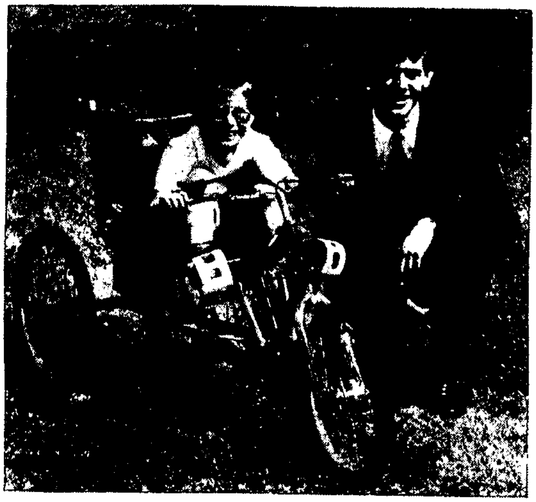

Figure 3 - The completed prototype tricycle

Kramer has since subjected the tricycle to many miles, including several family outings of more than three miles of riding! To date no significant problems have developed with the prototype. Several minor adjustments of the five speed hub have been made, otherwise the tricycle has performed very well.

DISCUSSION

The prototype tricycle successfully meets the major goals of the project described earlier. About $1800 was spent on parts, materials, and some of the machining. (The above figure does not include engineering time or the bulk of the machine work, which was donated.)

A second generation tricycle is currently being designed for a young cerebral palsy patient by a new team of mechanical engineering students. While the current model satisfied all of the design requirements, several improvements are contemplated. At about 50 pounds, the tricycle weighed more than expected; efforts will be made to make the second-generation vehicle smaller, lighter and more portable. It is the wish of the project team that the design benefit the widest possible range of disabled children. Discussions with several physical therapists from around the country indicates that there are many children with abilities similar to Kramer (many spina bifida and cerebral palsy patients, for example) and other than the HPV described here, there appears to be nothing available for these children to ride. The goal of the second generation team is to create a machine that is adaptable to as many children as possible while minimizing the cost of the machine.

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WHEELCHAIR LIFT CONTRAINDICATIONS

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Abstract

The number of handicapped individuals depending on transportation assistive devices increases everyday, especially with the help of the Americans with Disabilities Act of 1990. The disabled population travels in a variety of wheelchairs. Many of these individuals seeking an independent lifestyle through transportation in personal vehicles also face the need for a wheelchair lift. They also often encounter the difficult tasks of selecting an appropriate lift that matches their specific wheelchair and vehicle. Problems arise because of the lack of easily accessible dimensional information that will help one make these selections.

The objective of this project is to provide consumers, wheelchair lift prescribers, occupational therapists, and even manufacturers with a document to aid in matching lifts and wheelchairs and best fulfilling the needs of the disabled. One of the main obstacles to overcome is that of developing an objective but comprehensive method to educate and disseminate this information about devices available. The first problem lies in identifying the major dimensional interferences between existing lift designs and existing wheelchair designs. The second problem is understanding contraindications for wheelchair lifts in three major areas: safety, convenience, and reliability. By understanding these conditions, better decisions can be made prior to purchasing equipment.

Background

The idea for contraindications for wheelchair lifts was originally started by one of TREC's (Transportation Rehabilitation Engineering Center) staff members who also worked as an occupational therapist at the Woodrow Wilson Rehabilitation Center. It basically consisted of a preliminary list of observations about the interaction between wheelchair lifts and their users, focusing specifically on situations where the user's needs were not accomodated. It was noted that simple problems such as a steep safety flap (roll-stop) angle may be sufficient to prevent individuals on manual wheelchairs from using a lift.

The number and variety of problems recognized grew with TREC's involvement in evaluating the SAE's Recommended Testing Procedures for wheelchair lifts in personally licensed vehicles. A representative cross-section of lift types currently in the market has been used in testing the proposed standards and as a byproduct, specific strengths and weaknesses of these different devices were found.

This paper proposes the development and dissemination of a list of such lift contraindications and a method of objectively matching wheelchair and lift dimensional requirements through the use of a tabular matrix.

Methods

Lift Contraindications: As mentioned, the three main areas of concern when assessing wheelchair lifts are: safety, convenience, and reliability. In essence, these qualities found in lifts are all tied together. A reliable and efficient lift properly selected to accomodate the user and his/her lifestyle will most likely safely fulfill its purpose. Again, the contraindications should serve as precautionary information so that consumers may learn about the product their buying, what to expect, and how to qualify or disqualify lifts for their needs. At present, the contraindications are still presented in a "list" format and typical ones are shown in table 1.

A further step in this part of the project will be disseminate the current list of contraindications to the public for comments, additions and recommendations. It is still unknown how to best provide this type of information for most efficient use and implementation. The separation of the contraindications into specific categories following a checklist used to match the lift with personal requirements may be a feasible possibility.

Wheelchair and lift dimensional requirements: In many cases, the wheelchair or scooter is too long to fit on the lift in a safe manner. Either the wheels prevent the roll-stop barrier from locking into place or the or roll-stop flap interferes with the occupants feet. In other situations, the wheels of the wheelchair may get wedged onto the vehicle's side or bumper. Therefore safety and effectiveness are again major considerations.

The main concerns of this part of the

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• **Platform** lifts require ~ 8 ft. of space for exit from a lift. **Rotary** lifts need ~ 4 1/2 ft.
• **Manual Back-up Systems** are often time consuming. Those used in hydraulic lifts including gravity-down operation of the platform are easier and faster to operate.
• **One-arm Folding Platform** lifts tend to be less stable.
• The **Under-Vehicle Lift** may present problems with dirt build-up and penetration. Its main advantage is that it does not take up interior space or block the van door.
• **Arm Lifts** also allow for easy entry and do not block doorways. Applicability to different wheelchairs is questionable since loads are directly applied to the wheelchair frame.
• **Mechanically** or **hydraulically interlocked roll-stops** are more reliable and safer than **spring loaded** or **gravity activated** ones.

Table 1: Major Lift Contraindications

project were defining what wheelchair and lift dimensions to specify and how to present these guidelines in a simple format. Anyone interested in acquiring wheelchair and lift dimensions from manufacturers soon finds that each manufacturer has its own way of defining dimensions and taking measurements. In an attempt to use a widely accepted method, TREC chose the ANSI/RESNA WC93-1991 Wheelchairs Maximum Overall Dimensions standard. Information about a specific wheelchair model needs only two dimensions, the overall length and overall width, as shown in Figure 1. The length of wheelchairs generally range between 1100 and 1300 mm. The width of wheelchairs are generally between 600 and 700 mm. It is assumed that the user's feet add approximately 50 mm to the overall length.

Using these collected dimensions and the inside dimensions for wheelchair lift platforms, also measured as shown in Figure 1, a cross-reference matrix for compatible lifts and wheelchairs will be created. Basically, the overall length of the wheelchair, L, plus a minimum clearance of 50 mm should be less than or equal to the inside usable lift platform length. Likewise, the width of the wheelchair, B, should be smaller than the inside usable width of the platform with some minimum clearance yet to be defined. Taking measurements in this manner will actually result in a slightly conservative fit since the foot rest and person's foot are assumed to be inside the platform usable area. This means that the footrest is not hanging out over the roll-stop flap, which occurs in some cases.

The data on wheelchairs and lifts collected from the manufacturers is used to create a matrix like the sample on Figure 2 which cross-references wheelchair and lift dimensional compatibility. This quick reference table will serve as an immediate check for users and prescribers according to the measurement guidelines.

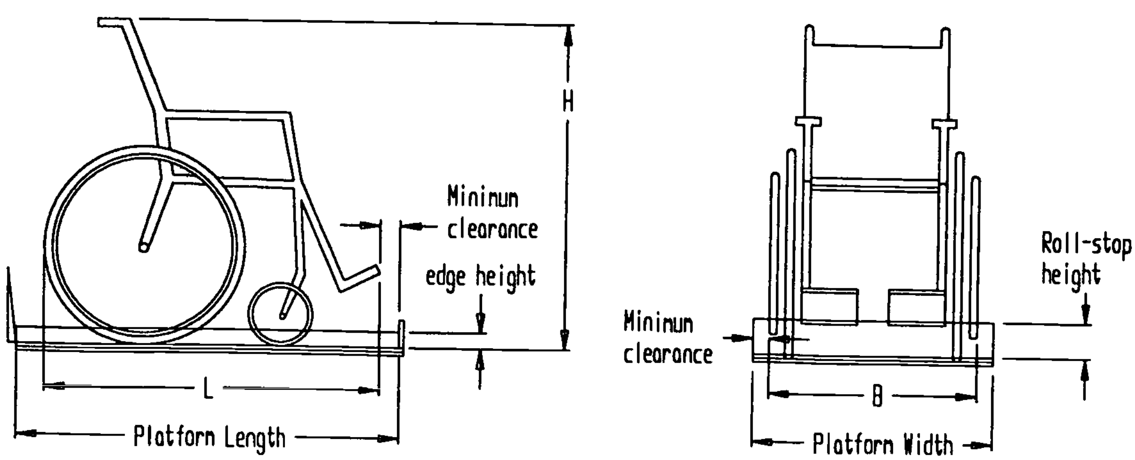

Figure 1: Appropriate wheelchair and lift measurements for these guidelines.

WHEELCHAIRS and SCOOTERS \ LIFTS		Ricon		Crow River		Braun	
		S1000 29W x 42L	S1001 29W x 44L	7688LA 29W x 42L	Vangater 30W x 42L	L401 29W x 42L	
Invocare	1000E 25.5W x 36L	✓	✓	✓	✓	✓	
	1000 25.5W x 32L	✓	✓	✓	✓	✓	
E. J.	Universal 22.5W x 36L	✓	✓	✓	✓	✓	
	Vista 22.75W x 31L	✓	✓	✓	✓	✓	
Fortress (scooter)	2000FS 24W x 43L	X	✓	X	X	X	

Figure 2: Sample schematic of the matrix of wheelchair / lifts reference. (The data shown is hypothetical and does not represent actual values)

Discussion

Although some information can be found in related literature, it is believed that occupational therapists and prescribers must rely mostly on their personal and professional experiences and their locally accepted guidelines when matching lifts with the requirements of their handicapped clients. An article recently published by Perr and Barnicle (3) accurately mentioned how complicated selecting the appropriate lift can be due to the variety of lifts and wheelchairs available, diversity of special needs of the disabled user and lack of information.

This project aims at making proper wheelchair and wheelchair lift selection easier for consumers and prescribers. By providing an objective document with information on contraindications for wheelchair lifts and what characteristics to look out for when matching personal needs with available devices, TREC hopes to educate people so that better decisions can be made. In order for this document to achieve its objectives, it will have to be reviewed and updated periodically, especially by active users and prescribers. Compatibility between the vehicle, lift, wheelchair and user's requirements is essential in making this technology work towards a safe and normal lifestyle.

Acknowledgements

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POSITIONING AND SECUREMENT OF RIDERS AND THEIR MOBILITY AIDS IN TRANSIT VEHICLES

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ABSTRACT

Individuals are transported daily in transit vehicles while seated on their mobility aids. Although federal standards exist to regulate this practice, there is controversy over whether the regulations are effective or practical. This paper describes the results of a study that performed an objective review of information available in several areas relevant to positioning and securing riders and their mobility aids in transit vehicles. The objective of the study was to present the current status of knowledge and to identify gaps in knowledge and related problems. As a result, recommendations are provided on future research needs and options for improvement of policy.

INTRODUCTION

Approximately two-thirds of an estimated 1.5 million mobility aid users require special transportation services (La Plante 1992). According to a recent profile of public transit passengers nationwide, an average of 1.2% of all transit riders have disabilities; the percentage may be 10%-15% in some communities (APTA 1992).

Accessible transportation allows people with disabilities to commute to work and school and to take part in normal daily activities. Accessible transportation includes various types of transit systems, such as fixed-route, demand-responsive, and paratransit services.

The 1990 passage of the Americans with Disabilities Act (ADA) is intended to help ensure adequate access, but the act does not specify the details of implementation. A number of controversial issues remain unresolved, including the best way or ways to provide safe, effective, and comfortable positioning and securement of riders and their mobility aids in transit vehicles. Much of the debate focuses on whether to position mobility aids in a forward-facing, rearward-facing, or angled securement system.

Federal regulations for transit vehicles currently mandate that the orientation of at least one of the required securement systems be forward facing; the remainder may be rearward facing with a padded barrier. Other orientations of securement systems are currently prohibited.

Some transit providers and consumers have challenged this ban on side-facing and other angled orientations, arguing that these orientations may be as safe with all factors considered (e.g., the use environment of the vehicle) and may provide other advantages, as well. Some providers believe that forward or rearward facing reduces vehicle capacity, resulting in a loss in quality and an increased cost of service. Consumers have also voiced concerns about ease of emergency evacuation, passenger comfort, and the users' ability to secure themselves unaided when in a forward- or rearward-facing position.

A number of potential information sources may facilitate an understanding of this issue, including legislation, regulations, and standards; accident statistics; and biomechanics and physical (crash) testing research. In addition, transit providers, consumers (mobility aid passengers), device manufacturers, and government agencies have various experiences and opinions.

The development of satisfactory solutions is hindered, however, because the knowledge base is distributed among many individuals and organizations. Overall system perspectives are not always readily apparent due to differences in objectives and compartmentalization of information. Information critical to this issue, though readily available, may be overlooked during studies because the group sponsoring or performing the study does not recognize this need.

This paper describes a study that performed an objective review of information available in several areas relevant to the positioning and securement of mobility aids in transit vehicles. The objective of the study was to present the current status of knowledge, identify gaps in knowledge and related problems, and recommend future research needs and policy direction. The scope of the project was limited to consideration of issues in vans, and small and large transit buses. Although school buses were not evaluated, information on these vehicles was collected and applied to vehicles within the project's scope.

METHODS

Information Sources

A panel of experts were drawn from representatives of government agencies, transit systems, consumer organizations, manufacturers, test facilities, associations, and others. The Project Review Committee (PRC) brought together expertise on the technical aspects of equipment and biomechanics, operational aspects of transit systems and consumer concerns; and knowledge of regulations, safety, and risk management issues.

An extensive literature search was performed. In addition, we collected information on commercially available mobility aid securement systems to determine the state of the art of this technology. We obtained information through

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personal contacts with PRC members and transit providers at conferences and meetings.

A survey of transit systems was developed to provide current, useful information that could not be ascertained from the literature. We designed the survey to provide accident data, transit fleet characteristics, and current practices for securing mobility aids and their users.

We developed a database to track and organize all documents gathered during the study. Each document in the database is classified according to the type of information it contains (e.g., documentation from crash testing, a review of literature, standards, regulations, conference proceedings); the database also includes abstracts for several documents. In addition, each document record contains 29 standardized topic fields. For each topic addressed in the document, the corresponding field is indicated. Users may search the database for all documents that address a particular topic; the database is intended to aid in future research efforts, as well.

Criteria and Method of Analysis

Based on the literature, our discussions with individuals and organizations, a survey of the experts in our steering committee and of transit providers, the following criteria are generally accepted as being important when designing and assessing securement systems. In practice, there will need to be tradeoffs between criteria, so we have listed the criteria in order of priority and indicated the general category into which they fall.

Safety:

1. Minimize injury to the occupant during impacts. Minimize injury to the occupant during normal driving and emergency maneuvers (e.g, swerving, hard braking).
2. Allow for egress in an emergency situation.
3. Simplify use of securement and passenger restraint devices. (If the devices are difficult to use, passengers and/or operators may not use them or use them improperly.)

Ergonomics/Human Factors:

4. Simplify use of securement devices by the operator and/or passenger, to allow for independent and timely securement.
5. Provide for the mobility aid users physical and mental comfort. For example, some orientations may cause nausea for some users or place them so that they are facing directly at other passengers.

Vehicle Characteristics:

6. Optimize vehicle capacity for conventional seating and mobility aid passengers. This significantly impacts the need for additional vehicles, scheduling, and cost.
7. Minimize costs (e.g., securement systems, installation).

Data were collected, organized, and analyzed in the areas of accident statistics, U.S. regulations, international standards and guidelines, physical testing research, biomechanics research, vehicle characteristics, ergonomics, and human factors. These areas were chosen based on a review of the literature and the concerns expressed by transit providers, consumers, researchers, and regulators.

SUMMARY OF FINDINGS

The main results of our analysis were:

- Existing accident data do not reveal the effect of mobility aid orientation on transit passenger safety. For example, the data do not conclusively indicate the predominant direction of impact for transit vehicles. The methods of data acquisition are neither uniform nor comprehensive and, therefore, cannot currently be used for the purpose of assessing the relative safety of various seating orientations.

  Limited data on injury-causing events for transit passengers riding on their mobility aids showed injuries to be primarily due to improper securement during normal and emergency driving conditions.

- U.S. regulations and most international standards require that mobility aid securement/occupant restraint systems be oriented forward or rearward with respect to the direction of travel and meet specified performance requirements. Requirements for systems' performance specify criteria under frontal loading conditions. Testing under lateral loading has not been developed.

- The physical testing of mobility aid securement and occupant restraint systems that was the basis for ruling out side-facing orientations was not intended to evaluate the best way to position passengers and their mobility aids. Qualitative analysis of test data showed that the systems tested provide inadequate protection when the mobility aid is in a side-facing orientation with respect to the direction of impact.

  Our combined analysis of the injury and excursion data from several physical testing programs did not reveal benefits of one orientation over another. The analysis contraindicates carrying out a testing program, at this time modeled after these research programs, to answer the question of how best to position a mobility aid.

- Information collected on passenger biomechanics and human tolerance limits indicates that the occupant is at a greater risk of injury in the side-facing orientation. Frontal impacts result in the most severe crash forces and the human body has a reduced tolerance to lateral loads.

- Research and development efforts in occupant protection have been geared toward protecting passengers in the forward-facing orientation. As a result, product development of mobility aid securement and occupant restraint systems has focused on achieving safety in this position under extreme conditions of frontal impacts. Lateral stability and injury prevention has not been developed.

- Capacity reduction in transit vehicles appears to affect smaller vehicles and to be a result of compliance with a variety of ADA requirements. It does not appear to be due to orientation requirements alone. Research into optimal vehicle layouts and use of innovative seating technology may reduce capacity problems.

- No collected data indicated a choice of orientation based on ergonomic and human factors. Once an orientation has been chosen, innovation in vehicle layout and securement system design should address and resolve problems in these areas.

- An indirect conclusion is that there is a need for development of a procedure to determine if certain mobility aids should be occupied during vehicle transport.

CONCLUSIONS AND RECOMMENDATIONS

Research Issues:

1. Do not pursue a research program consisting of sled testing of angled mobility aid orientations (including 90°) at this time.

2. Support research into improved securement systems for mobility aids.

3. Support further research and development of testing programs that qualify mobility aids for use on transit vehicles.

4. Pursue the development of test methods and criteria for testing side-facing or other angled securement and occupant restraint systems for equivalency *and* for testing the stability and protection of forward- or rearward-facing systems under lateral loads (e.g., swerving, side impacts).

5. Pursue research into optimal vehicle layouts and use of alternative seating technology in vans and small buses to meet the needs of transit providers.

6. Support efforts to gather better transit accident/injury data prospectively for transit incidents through development of a database for problem reporting.

Policy Issues:

1. For the present, support the policy of requiring forward- or rearward-facing mobility aid securement systems based on the results of the collective analysis of the data. Sufficient data do not exist to show that an angled orientation (including side facing) is equivalent in safety to the forward- or rearward-facing orientations or that it will provide significant advantages.

2. Examine the policy requiring transit vehicles to transport riders seated in all "common" mobility aids. Until further research and device improvements are performed, not all mobility aids can be transported safely while occupied.

In summary, the study recommended that, for the time being, the regulations should continue to require forward- or rearward-facing securement systems. At the same time, it recommends development of performance criteria and test methods that will ensure the safety of securement/occupant restraint systems under side-loading conditions, allowing for innovation and improved safety.

The study further recommends that research must be performed in the areas of mobility aids, vehicle layouts and seating systems, and securement/occupant restraint systems and the procedures used to test them to aid transit systems in implementing the ADA without compromising safety or the quality of service. In addition, creation of a problem reporting system would be useful for assessing the needs for improvement in technology and transportation procedures.

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Augmentative & Alternative Communication

A COMMUNICATION SYSTEM ESTABLISHED FOR A C-5 QUADRAPLEGIC AND HIS HEARING IMPAIRED PARENTS

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Abstract
A young man loses the ability to communicate basic needs and emergency situations to his hearing impaired parents secondary to his high level spinal cord injury and closed head injury. The patient's rehab team considered this situation unsafe for the patient to return to his home environment since he had several medical complications. This paper examines the special needs of this patient and his family and describes how the team was able to establish a safe home environment for this young man once he was discharged from the hospital.

Background

Medical History/Psychosocial Status

John, a 17 year old male, was rendered quadriplegic and sustained a closed head injury following a motor vehicle accident on 1/11/93. Initially, the patient was able to open his eyes and follow directions and move the upper extremities. On 1/21/93, the patient underwent an emergency tracheostomy secondary to desaturation, bradycardia and a seizure. The patient was noted to have a neurological decline secondary to unresponsiveness and less movement in the upper extremities. The patient was transferred to Shepherd Spinal Center on 2/17/93 where he was diagnosed with C-5 complete quadriplegia and TBI status post-anoxic event. One other complicating factor in John's admission was his Grade IV sacral decubitus which required surgical intervention. John's rehabilitation course was delayed secondary to his confinement to the bed for eight weeks following surgery.

John's parents are both completely deaf and his father is visually impaired as well. Premorbidly, John communicated with his parents through sign language. John also has an older sister who has normal hearing. John's sister did not live at home at the time of the accident but moved back home after the accident. The sister stated that she did not want to be responsible for all of John's care once he came home since she worked and had a life of her own. The family has limited financial resources and lives in a first floor, three bedroom apartment in a rural town. John's grandmother, aunt and cousins live in the same town, although are not within walking distance to John's apartment.

John attends school at the local high school approximately 3 miles from his home. In September of 1993, he will be in the eleventh grade. John's personal goal was to return to school. John was considered a good student prior to his accident and was very interested in pursuing art. John was a talented artist and many of his drawings were displayed in his hospital room. Other interests include reading and watching movies and sports events on television with his father.

Problems

Acutely, John was not able to speak secondary to his trach tube. He also exhibited severe dysarthria initially as a result of his head injury and was unable to even mouth words. John became very frustrated with his difficulty communicating with others, especially his parents. John was paralyzed below his shoulders and had very limited range of motion in his shoulders and neck secondary to severe tone. It was therefore impossible for John to use conventional sign language to communicate with his parents.

Although John regained the use of his voice and speech sufficient for hearing persons, his inability to communicate with his parents raised the question of John's ability to return home and live safely with his parents. John was prone to autonomic dysreflexia secondary to his high level of spinal cord injury. This condition is life threatening and needs immediate attention. John was also not able to control selected environmental functions secondary to his physical limitations.
John was dependent for all functions that take place in the school setting.

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Objective

John's rehabilitation team met weekly to discuss John's goals, problems and progress. The rehab team consisted of the pediatrician, nurse, occupational therapist, physical therapist, speech pathologist, social worker, school teacher, psychologist and rehab technologist. During these meetings, John's discharge plans were discussed and decided. Many times the issue of whether or not John's parents would be able to safely care for John at home was discussed. John's parents were not able to hear John if he called for help and they were not able to understand what he needed at any given time. It became the mission of the team to establish systems in the home that would enable John and his parents to effectively communicate and to decrease the potential for problems to a minimum. The team also was interested in setting John up with systems that would enable him to return to his school so that he could finish high school and pursue college.

Method/Approach

John was referred to an Assistive Technology Team by his occupational therapist in order to evaluate and experience different systems that would meet the needs of both John and his parents. The Assistive Technology Team, consisting of a speech pathologist, rehabilitation technologist, and assistive technology occupational therapist, evaluated John for a system that he could easily utilize when he needed to get his parent's attention or in the case of an emergency. Components of the system are listed below.

Seating and Mobility
John was positioned in a power tilt in space wheelchair to prevent shearing on his sacral area and to prevent increased tone when doing mandatory weight shifts every 30 minutes. John was eventually able to develop enough strength in his right upper extremity to be able to drive his wheelchair with a hand control. Prior to using the hand control, John had become proficient in using sip and puff to control the chair. A Plexiglas laptray was also prescribed for John to support equipment and schoolwork.

Emergency call system
John used sip and puff switch access since he had limited use of bilateral upper extremities. It was recommended that John have an emergency call system that flashed lights in the house and activated a bed vibrator so that his parents would respond to the call. An X-10 based system was recommended. John was issued the X10 transmitter/receiver, a sip and puff pneumatic switch with a gooseneck mounting system, 5 appliance modules, 5 flasher buttons to make the lights flash, and a bed vibrator. John was also issued a speaker phone adapted with a sip/puff switch to allow limited independent telephone operation. The speaker phone could be used as a backup system in case his parents could not understand what he needed. The speaker phone had 911 preprogrammed so that it would be easy for John to contact emergency help.

John's rehab team made a home visit to John's house in order to set up the equipment and to train the family on its use. During this visit, calls were made to the local police and fire department and to the local hospital to let them know that John would be returning home.

Communication Needs
John was in need of a communication system that would allow him to communicate with his parents in a consistent manner. After many trial and error sessions in occupational therapy, John demonstrated his proficiency with the Prentke-Romich Head Master as a computer access tool. This device operates the cursor with head movements and sip and puff. The team then set out to find a computer program that could be utilized with a portable computer that would allow John to spell out what he wanted to say and also display pictures of what he was expressing. The pictographs were necessary as John's father had difficulty seeing the computer letters and both parents have low educational levels. John's speech pathologist recommended the computer program "Speaking Dynamically" for Macintosh computers after review of several programs.

An Apple Macintosh PowerBook 180 laptop computer was also recommended for John. It was important that this specific computer be recommended as the technology team evaluated the readability of the screens for both pointer visibility when used with the Head Master and also visibility with John's mother and father. This computer was the only one that provided active matrix black and white displays that approach the quality needed for contrast, size and angle viewing. John and his parents underwent intensive family training to learn this Communication system. It was necessary to hire a sign language interpreter to help teach the parents the system. The family participated in training daily for one and a half hours per day, 5 days a week for 2 and a half weeks. Training continued until both parents could demonstrate their ability to correctly and consistently use the communication system Eventually, both John and his parents were able to prove their understanding of the system when they completed a therapeutic pass inside the hospital for 48 hours with no assistance from the staff in John's care.

A Daessy Folding Mount was also recommended so that the laptop computer could be mounted to John's wheelchair. A power inverter was recommended to allow the portable computer to be tied to the wheelchair batteries for extended periods of operation.

School

In order for John to return to school, he needed to be able to use a computer to complete his assignments. His laptop computer can easily meet his needs with the following software additions.

-ScreenDoors 1.1 for the Macintosh using System 7.: This software program emulates a keyboard on the screen and has word prediction. This allows John to type his papers with the HeadMaster.

-Claris Works 2.0: This software program includes a word processor, spreadsheet, database, telecommunication and drawing functions.

-Professor Mac: A tutorial software program for the Apple Macintosh.

A HP Deskwriter for Mac was the recommended printer and a Practical 24/96 Fax Modem was also recommended so that John could easily print out his work or could fax his work to the school if he became confined to his home for any reason.

Funding

Funding for the recommended equipment became a real issue when John was ready to be discharged. John's insurance coverage was limited and standard and would not cover his very specialized equipment needs. The rehab team applied for and obtained a private grant that funded the equipment that would enable John to be safe in his home. John's high school held a fund-raiser that raised the remaining funds necessary to obtain John's school equipment.

Results

John was discharged home with his parents on August 4, 1993 with plans to return to school at the end of August. Since John's discharge, John's rehab team has been communicating with his school to inform them of his needs in the school setting. John was also referred to occupational therapy in the school so that he could receive further computer training once he received his software.

Discussion

The integration of a variety of environmental control units, a computer and computer program and a method of access, has allowed a young man to return home with his family and return to school. Many hours of team problem solving, experimentation and training had to occur in order to allow this to happen. The availability and compatibility of certain types of technology allowed the team to come up with a solution that at one time seemed impossible.

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DEVELOPMENT OF AN ASSISTIVE TECHNOLOGY SUPPORT NETWORK

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Abstract
The goal of this project was to increase opportunities for interaction, control and communication by adults with developmental disabilities in both their day program and group home settings. An integrated program of community-based service delivery, staff training and consultation was developed to meet these needs.

Background
This project developed a community-based assistive technology intervention model for the improvement of interaction skills in severely developmentally disabled adults.

The project was divided into two phases. During the start up phase, two group homes were used as field sites for development of the community-based assistive technology intervention approach and model. During the transition phase of the project two additional group homes were selected for replication of the program.

Objective
The overall goal of this project was to develop a model program for development of local AT support networks which facilitate interaction and communication for adults who live in residential care facilities and attend day programs. Specific objectives were to: (1) identify and describe a framework for cost effective community-based AT intervention, (2) develop program guidelines that can be used for replication, (3) develop a training program and materials for training direct care staff, (4) develop program materials for consumer training.

Method/Approach
During the start-up phase we developed a collaborative consultation/training model for intervention. This model included a large training component and materials were developed. These resource materials included suggested equipment lists, recommended activities for participant training, and data collection procedures and forms. Training sessions were videotaped for use in developing materials and for use with new staff. Further training of direct care staff occurred during collaborative consumer training sessions. A set of forms for assessment, intervention planning and monitoring progress were also developed. Equipment utilized in the training was supplied to each group home by the project. Within each group home and day program a resource person was identified. This was essential for establishing lines of communication and the level of support required by direct care staff.

Both formative and summative evaluation were employed to evaluate the impact of the project on the assistive technology skills of the direct-care staff and the program participants. A pre-test addressed initial assistive technology know-ledge and attitudes, as well as perceptions of consumers interactive skills by the staff. Following staff and consumer training, post-tests were utilized to assess learning. Direct-care staff also provided informal evaluation of all project activities.

Low-technology approaches were also included through consultation on the design and development of communication boards which can be utilized by consumers. Our materials included an environmental communication survey which identified communication opportunities for participants and resulted in suggestions for specific vocabulary to be included on communication boards.

As the program developed, and consumers and staff developed greater AT skills, it was necessary to set new goals and make adjustments in the training programs.

During the transition phase, we replicated the intervention model at two additional group homes. This phase allowed us to evaluate our model and materials in a mode very similar to that which will exist during the post-project continuation phase. During this phase, consultation was provided in at least one session per month per group home. Direct care staff provide on-going training of consumers between these sessions.

Results

Training materials were developed for three audiences: (1) professional consultants to the group home or day program (speech pathologist, occupational therapist), (2) direct care staff and (3) consumers. For the first two of these competencies were developed. For each consumer intervention goals were established.

The pre-test results indicated a general lack of familiarity and comfort by staff with computers and other technologies. Following training, the staff became more comfortable with the computer, and they were able to independently use it and the other technology with the consumers in their programs.

Discussion

Personal computer-based and low-technology equipment for training and evaluation was used. Since it was possible to simulate participant interaction with an individual communication device using the computer, this approach allowed determination of whether a specific device would be successful for a given individual. Since the training and evaluation can occur over a prolonged time period, this approach gave the consumer a "fair chance" at achieving success without the purchase of an individual device. Since funding agency funds won't be expended for an individual device until successful use is demonstrated based on a computer simulation, costly "mistakes" in equipment acquisition can be avoided, and the likelihood of success with the individual device which is eventually chosen will be greater.

The consumers participating in this project improved both their control of the environment and their ability to communicate. Both of these lead to greater participation in daily activities and an intensified role in self-determination.

The perceptions of the direct care staff towards technolgy and its benefit for the consumers also changed significantly.

Acknowledgements
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Appendix
Equipment utilized- Computer system: MacintoshLC w/AppleIIE card, Ke:nx[1], Echo LC speech synthesizer, color monitor. Control interfaces: enlarged keyboards[2] switches: tread and lever[3], wobble[4], big red and jelly bean[5], universal switch mounting[5]; Ablenet Appliance Control Unit, battery adapters[5], single switch Ultra-Four transmitter/ receiver pairs[6].

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A HEAD GESTURE RECOGNITION SYSTEM FOR COMPUTER ACCESS

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ABSTRACT

This paper describes work done in the recognition of head gestures at Cambridge University. The aim of this work is to enable quadriplegics and individuals with various muscular disorders to interact with computer applications and to communicate with their environment. The approach to the problem uses template - based recognition techniques to achieve real - time recognition of a gesture vocabulary of variable size. The calibration of the recogniser is achieved by using a software package, which optimises the procedures for an individual. These procedures can then easily be incorporated into any application involving a human - computer interface. Preliminary experimental results obtained from trials with subjects who have athetoid cerebral palsy are presented.

BACKGROUND

Certain individuals suffer from severe handicaps such as high - level quadriplegia, cerebral palsy and other neuromuscular disorders, which restricts their access to computer - based applications or communication aids and limits their capability to control their environment. This limited communication can have traumatic psychological effects on both adults and children, and the lack of manipulative ability may prevent children from following the natural learning process. Typical computer access methods include keyboards, joysticks, mice and touch pads, all of which are useless to users without some manual dexterity. Speech recognition systems offer a partial solution to the problem, but some severely handicapped users are dysarthric and can therefore satisfactorily control only their head muscles .

Substantial research work has been done in the recognition of head gestures, using techniques such as hidden Markov models, neural networks, and finite state machines[1][2][3]. These procedures have generally been tailored to particular applications, and have not been flexible or easily accommodating to any changes in the user's ability to perform head gestures.

This paper describes the design and development of a gesture recognition system that can run on a 386 or 486 based personal computer. The training of the recogniser is simple and fast, and once trained can be incorporated in any computer application being developed. The set-up used in the user trials consisted of a 386DX based computer with a 387 maths coprocessor. A Polhemus 3Space Isotrack transducer mounted on a baseball cap was use to measure the head position. The decision to use the Polhemus was one of availability, but similar performance would be expected from a cheaper head position sensor.

PROBLEM STATEMENT

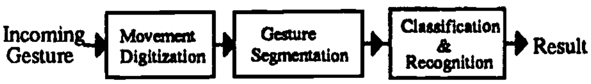
In order to design an effective gesture recognition system, certain design requirements had to be fulfilled. These can be summarised as follows:

- The system must be simple to use.
- It must be inexpensive.
- It must have the ability to adapt to an improvement or deterioration of the user's ability to perform head gestures.
- Its gesture recognition accuracy must be high.
- The system should be trainable on small amounts of data.
- It should be able to cope with a range of gesture vocabularies.
- It should be easy to incorporate in the development of computer applications.

It is important to note that due to the large variation in disability type and severity, it is practically impossible to design a user independent recogniser. It is possible, however, to minimise the variables needed to define the characteristics of the recogniser, and to make its calibration simple and user friendly. Furthermore, although the recogniser should cope with a range of gesture vocabularies, it was thought useful to define a base vocabulary of gestures. This has the advantage of providing software developers with a minimum vocabulary of gestures to incorporate into their applications, as well as establishing a minimum level of ability required to use such a system. The gestures used in the base vocabulary should be intuitive and easy to perform. A set of six simple gestures was hence chosen, namely Up, Down, Left, Right, Yes and No. In addition to these simple 'directional' gestures, the user can choose other gestures to add to his vocabulary. These gestures are described as complex, and the current limit is set to nine additional complex gestures, making a total vocabulary of 15.

DESIGN AND DEVELOPMENT

The gesture recognition process can be defined as follows:



The head movement produced is digitised using a Polhemus 3 Space Isotrak transducer sampling at 60Hz. It provides the computer with a six - dimensional data vector containing three translational parameters and three rotational parameters of a head mounted sensor with respect to a stationary source. The gesture data is communicated to the computer in serial form.

Once the head movement information has been digitised, the gestures need to be segmented, in order to define their start and end points in time. Segmentation of the gestures is performed by using a tremor filter. The tremor filter used in the recogniser consists of a first in first out (FIFO) buffer of fixed length which is updated after every sample. The tremor in each axis is measured by taking the variance of the head position over the time span defined by the buffer length. There are two tremor thresholds which are implemented in the segmentation process, namely the still threshold and the movement threshold. The still threshold determines when a person's head has gone from a still state to a moving state, while the movement threshold determines when the head has returned to the still state after having completed a gesture. Both thresholds are user dependent and are determined probabilistically by the calibration software, so that in each head state, the probability of the segmentation algorithm being correct is 95%.

When considering which recognition techniques to use, we examined stochastic and connectionist recognition techniques such as neural networks and hidden Markov models. These techniques require large amounts of data to train, and it is difficult to design a system that can easily adapt itself or be retrained to account for a change in the way the user performs gestures. It was therefore decided to use a template - based technique as the basis of the recognition process. Template based techniques compare a time - varying signal to a group of predefined templates or of the signal and assess their similarity. They are comparable in speed with the aforementioned approaches and can be retrained by simply replacing the gesture templates. In this particular case, a process known as Dynamic Time Warping (DTW) was used, and satisfactory results were obtained from only one template per gesture.

DTW has successfully been used in speech recognition, and the recognition of hand gestures [4]. It is an optimisation technique whereby the vector distance between two finite, time varying signals is calculated, after the difference due to varying signal lengths has been minimised. Waibel and Lee provide a comprehensive reference on DTW [5].

A process known as principal coefficient analysis (PCA) is used to classify the gestures, before they are recognised by the DTW algorithm. This has the advantage of reducing the number of templates the DTW algorithm needs to search through, thereby increasing the recognition speed. PCA performs the following operation on the gesture data representing the three rotational axes of the head:

$$PC_{ax} = \sum (x_{axi} - \bar{x}_{ax})^2 \qquad (1)$$

Where: PC_{ax} is the principal coefficient of axis ax
x_{axi} is data point ax in the ith vector of the gesture sequence
$\bar{x}$ is the mean value of x_{ax} in the vector sequence

Since directional head gestures are dominated by movement in one axis of rotation, it is possible to distinguish them from complex gestures by looking at the principal coefficients obtained. The principal coefficient analyser performs this task by examining the Principal Coefficient Factor (PCF), which is defined as:

$$PCF = \frac{PC_{max}}{PC_2 + PC_3} \qquad (2)$$

Where: PC_{max} is the largest principal coefficient
PC_2 and PC_3 are the remaining two principal coefficients.

If a gesture is directional, the PCF will be high since PCmax>>PC2+PC3. The PCF threshold value that distinguishes a directional from a complex gesture is user dependent, and is one of the recogniser parameters that needs to be set using the calibration software. Apart from classifying a gesture as directional or complex, PCA is also able to determine whether the gesture performed was mainly horizontal or vertical thereby further reducing the number of candidate gestures.

HEAD GESTURE RECOGNITION

This section has described several variables in the recogniser that are user dependant. In order to enable non-technical people to optimise these variables for a particular user, a software application called the 'Gesture Recognition Workbench' was developed. This application calculates the tremor thresholds and facilitates the adjustment of all the user - dependent variables, as well as providing the facility to create gesture templates. Once the recogniser has been calibrated, the variables are stored in a file which is automatically loaded every time the recognition system is used in an application.

RESULTS

Testing of the recogniser with six disabled subjects is being undertaken. Five subjects have varying levels of athetoid cerebral palsy, while one of them (D3) has Friedrichs ataxia. The preliminary results presented here are based on an eight gesture vocabulary, namely the base vocabulary and two optional gestures chosen by the subjects. The vocabulary was kept small due to the fact that the subjects were not trained in performing complex gestures, and the test was fairly strenuous. The test consisted of the subjects being requested to perform each gesture in their vocabulary 10 times over a random sequence of gestures. An observer later examined video tapes of the sessions in order to provide a comparison between the human and computer recognition capability. This proved to be a useful indication of performance, as some subjects performed gestures which were clearly not recognisable.

PRELIMINARY RECOGNITION RESULTS

Subject	CRA	NRA
D1	88.8%	92.5%
D2	44.2%	54.6%
D3	87.2%	97.4%
D4	85.0%	95.0%
D5	82.5%	90.0%
D6	98.8%	98.8%

CRA = Computer Recognition Accuracy
NRA = Normal Recognition Accuracy

The results show that the computer recognition accuracy was on average only 6.3% below the human recognition accuracy. This figure is relatively low considering that a human observer can obtain visual clues, such as eye movement or facial gestures of the subject, that will aid in identifying the head gestures. The computer on the other hand, relies solely on the stream of position vectors produced by the Polhemus to identify the gestures.

Both recognition figures are expected to improve as the subjects get more practice at performing head gestures.

FUTURE DEVELOPMENTS

The disability this research is concentrating on is athetoid cerebral palsy. In the near future we expect to analyse the movement 'noise' inherent in athetoid cerebral palsy, and attempt to extract it from the gesture movement. This should considerably improve the recognition rate.

Two applications using the gesture recognition system are also currently being developed. One is an application aimed at young children which teaches them aspects of shape recognition. The second, is a head gesture assisted direct control system for a robotic manipulator[6].

ACKNOWLEDGEMENTS

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The Design and Development of a Computer-Based System for Assessing and Training Two-Dimensional Language Representation

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ABSTRACT

This paper describes a system that can be used in the design and delivery of picture-based instruction for AAC users with severe cognitive impairments. The system design, which is based on previous research in picture understanding, allows interventionists to create images that are abstracted along the dimensions of color, size and detail. These images can be embedded in instructional protocols used for assessment and training.

BACKGROUND

There are many individuals who cannot benefit from current picture-based instruction and augmentative communication interventions because their cognitive skills are not sufficiently advanced to permit understanding of pictured information. (1-4).

The Mineo study (4) demonstrates that, in order to fully assess client strengths and weaknesses in regard to various levels of representation, we must be able to systematically manipulate the size, color, and quality features of the stimuli. A system capable of such stimulus manipulation would permit a comprehensive and precise evaluation of client skills. This in turn would ultimately result in the selection of intervention materials appropriate to the client's level of functioning.

There is evidence that we can advance an individual's ability to understand two-dimensional representations through the application of systematic training procedures (5, 6). Thus, an instructional system that is capable of manipulating the size, color, and detail of graphic representations could be used to generate stimuli, that could be incorporated into a training paradigm based on proven instructional principles.

RATIONALE

The evolution of computer-based technology, especially in the area of graphics quality, has created the potential to create such an instructional system. This paper discusses progress made in the development and evaluation of an Apple Macintosh-based application that can be used for assessment and training of picture understanding skills (7). It applies a variety of interactive and automatic image processing functions to provide an interventionist with the ability to easily manipulate image abstractions. This component is combined with the capability to embed these images into instructional screens and to define scripts that control the instructional protocol and data collection.

DESIGN

The system design reflects the task requirements of image manipulation and protocol development. It is comprised of two major components: the *Image Browser* and the *Protocol Browser*. Combined they support the design and delivery of instructional protocols that can be used to assess or train an individual's picture understanding along the dimensions of size, color, and detail.

Conceptual Model

The features *size*, *color* and *detail* can be thought of as dimensions in a space of possible picture representations (Figure 1). Along each axis, a number of characteristic pictures can be defined. The origin is described as a full size color photographic quality representation. Along the size dimension, the representation ranges from full-size to miniature. Along the color axis, the representation ranges from full-color to gray-scale (as in a black and white photographs) representation. Detail as we have defined it ranges from photographic quality to line drawing, but we have also defined an intermediate point that is cartoon-like; that is, it consists of a relatively small number of colors that are used to create solidly shaded areas of important features.

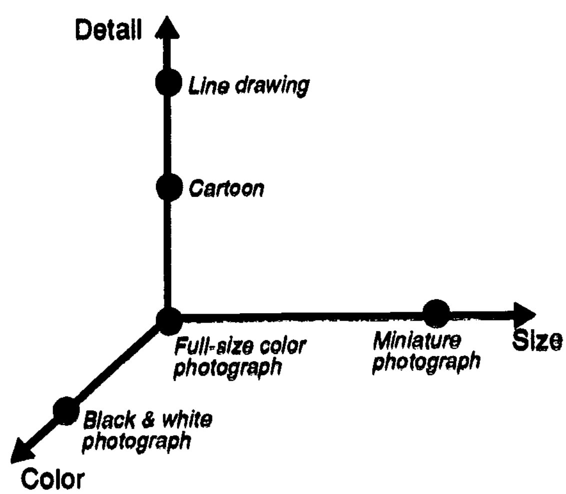

Figure 1. Picture space as a function of three dimensions of abstraction.

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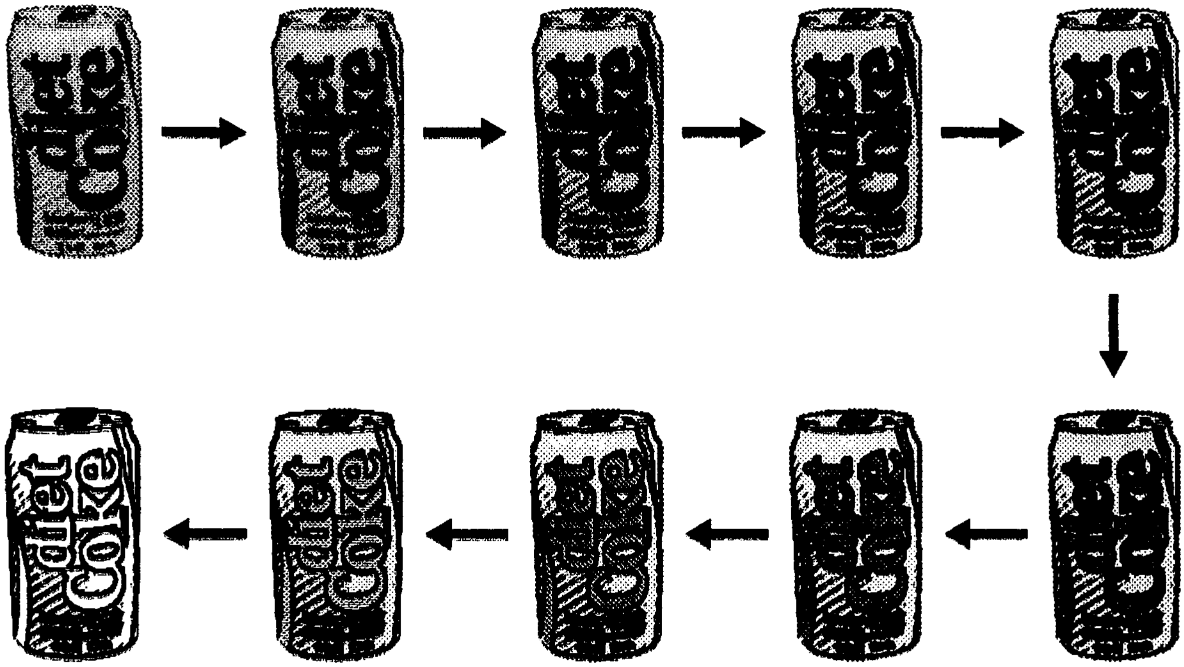

Figure 2. Incremental progression from photograph to line drawing

It is important to understand that these axes define a continuum of representational possibilities. A specific representation can exist anywhere in this space (since these features are independent) and not just along the axes. In addition, it is possible to specify as fine an increment as is needed to advance a user's understanding. Figure 2 shows a progression from photograph to line drawing along a sequence of ten representations.

Image Browser

The Image Browser is responsible for image acquisition and image manipulation. Acquisition is supported through an import feature that reads TIFF files (a common interchange format) that are produced from either a video-based capture system or scanner. Image manipulation is a multiple step process that includes image preparation, abstraction preparation, abstraction definition, and abstraction creation.

Image Preparation - The image preparation phase includes the process of masking and cropping. *Masking* removes the image background from the object, allowing it to be displayed on the white screen background without a trace of its rectangular photographic origins. While it is possible to photograph an object on a solid white background, it is almost impossible to totally eliminate subtle color and shading differences between the resulting image background and the screen background. *Cropping* is simply the process of eliminating any of the background area that is extraneous to the object. It defines a bounding rectangle around the object that is used in subsequent display and sizing operations.

Abstraction Preparation - The abstraction preparation phase is necessary to support manipulation along the dimension of detail. While size and color abstractions can be created automatically from parameters, detail requires the creation of two intermediate images. The first is a line-based representation that can be created by applying an edge detection algorithm. The second representation is used for cartoon-like images and consists of a small number of colors. This can be obtained through a process called quantization, where the image is analyzed for its dominant colors and is then remapped using this small set. These two representations along with the original image can then be blended to form intermediate representations along the detail dimension.

Abstraction Definition and Creation- For a given protocol, the interventionist must decide which abstractions are to be manipulated and how finely they should be varied. During this process, a series of named abstractions are created that define the representations to be used in the protocol. They are similar to named styles used in many word processing programs. During this process the interventionist defines numeric parameters for each dimension (size, color and detail) through a dialog box. Subsequent to this definition process, abstractions can be applied to any of the images that were brought into the system.

Protocol Browser

The Protocol Browser allows a clinician to define a series of instructional screens. Each screen defines an arrangement that corresponds to the desired instructional task. For example, a matching task might involve a full size photographic representation at the top of the screen with four abstract representations at the bottom. Each screen can then be instantiated with specific images that have been defined in the Image Browser, or the system can assign images according to a specified randomization criteria. The second part of protocol development involves defining an instructional script. The information contained within the script includes the duration that each screen is shown, inter-stimulus intervals, prompting, and actions to be taken based on student input. Currently, scripts must be developed using C++, but future versions will include a user accessible interpreted scripting language.

DEVELOPMENT

The prototype software has been implemented on an Apple Macintosh Quadra 900 with a 24 bit graphics adapter, video and scanner input, and removable mass storage. The application is written in C++ using the Apple's MacApp™ application framework. Major software components include the graphics data model, user interface components, and image processing routines.

In the design of the Image Browser, a number of interesting design solutions were developed that combined traditional image processing techniques with interactive control. For example, tradition quantization automatically creates reduced color images from a source image and a specification of the number of desired colors. Unfortunately, most algorithms have not been designed to work with a very small number of colors (e.g., less than 10). We have developed an interactive quantization technique that allows the user to "pick" the desired colors directly from the image. The system then re-maps the image to the desired color set. This has the advantages that color selection is perceptually-based and, by virtue of the fact that it is interactive, the user can try different selection sets until the desired result is obtained. This is not possible with an approach that is based solely on automatic quantization.

EVALUATION

The current system has undergone an extensive internal evaluation. This alpha testing, which has been primarily limited to the Image Browser, has uncovered a variety of software bugs and problems. For example, the masking process was found to be inaccurate with certain objects such as a comb. In addition, a number of additional features have been suggested through this phase. The system is scheduled for field testing in the spring of 1994. During this phase a test protocol will be evaluated with a number of students who have cognitive limitations.

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THE SPEECH TRANSLATOR - A COMMUNICATION AID FOR SEVERELY IMPAIRED SPEAKERS

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ABSTRACT

The aim of the project is to produce a unit that recognises the distorted utterances of a severely impaired speaker, which are often very difficult for the listener to understand. The translator then speaks a word or phrase with a speech synthesiser that the listener can understand. The device has therefore been called a 'speech cleaner' by some. We have had field trials with a number of potential users.

BACKGROUND

Development of a translator communication aid for severely impaired speakers has been under way for two years. The concept of recognition of non-verbal utterances has been proposed before (1,2), but people with inconsistent vocalisations, eg some cerebral palsied individuals, have not been able to use the devices. New technology presented here allows them to do so.

DESIGN

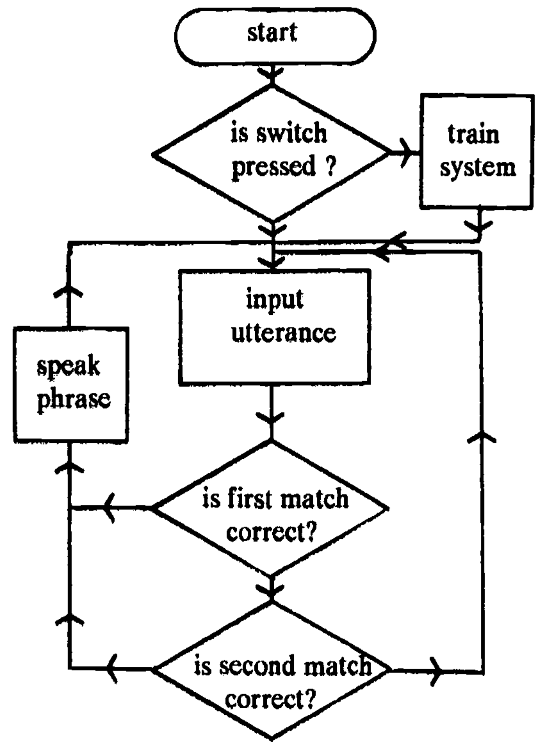

Figure 1. Programme flow

a) Software

The recognition technology used has been developed at the Royal Military College of Science (RMCS), Cranfield University, Shrivenham, UK (3,4). The time encoded speech (TES) method used functions well in noisy environments. In addition, and more importantly, the method can recognise the repeated, elongated or stuttered utterances typical of many disabled speakers.

We have developed the user interface for a TES recognition unit using a single switch input and a small liquid crystal display. The programme flow is illustrated in figure 1. Training of the translator is done by the user repeating the word five times, and at present storage of ten distinct utterances are possible. The phrases and words stored in the unit can be edited by connection of a computer terminal or by the LCD display.

b) Hardware

The system is based around a Bowman 68010 microprocessor board (SDS Ltd, High Wycombe, UK), with 1 Mb of ROM/RAM memory space. Custom boards built by RMCS Shrivenham perform the analogue signal processing and coding. Figure 2 shows a block diagram of the system.

EVALUATION

Clinical trials have been carried out with 15 users and the feedback has been very encouraging.

The system has throughout demonstrated extremely well its ability to recognise stuttered or elongated speech inputs. Various distortions have been imitated, with performance results being the same as with normal speech.

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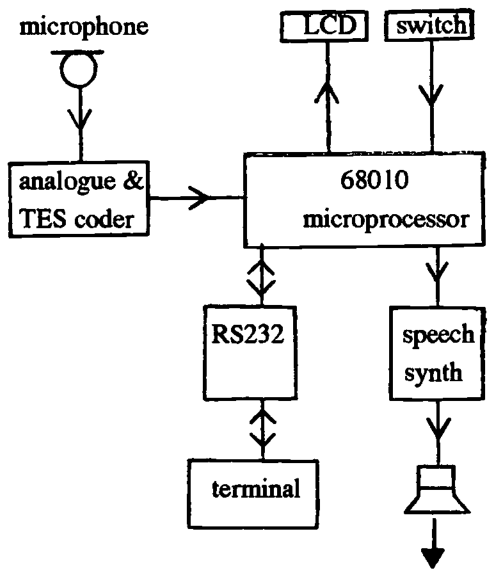

Figure 2.
System hardware block diagram.

Enthusiasm for these demonstrations of the concept has been high amongst potential users and therapists alike. RMCS Shrivenham have demonstrated recognition accuracies of 96%, even in the presence of high background noise.

Clients have been taken from a number of groups of disability, on the suggestion of the therapists involved who saw applications for several different groups. These included cerebral palsied children and adults (4), Downs syndrome children and adults (2), adults with learning difficulties (3), adults with compound disabilities including profound hearing loss (3) and adults with severe head injury (3). Other groups suggested have been people with Parkinson's disease, strokes and laryngectomies.

During trials, clients have suggested a number of areas of use for the device. These ranged from communication in the home and institution to shopping, cinema and other leisure uses, given that the translator would eventually be more portable.

DISCUSSION

Further development of the device is planned. This will include a new speech synthesiser, development of the user interface arising from clinical trials results and miniaturisation of the unit in order to make it portable. The use of a switch for operation of the unit should also be questioned due to the level of motor control required for simultaneous speech and switch use. This could be done by use of a sound operated switch being sensitive to the presence of an input, but the practicalities are difficult and require detailed consideration. These and other developments would enable formally assessed trials to take place.

This further work is currently under consideration. The technology is undoubtedly a major advance for severely impaired speakers, enabling them to have access to some of the enormous benefits speech recognition technology can bring.

ACKNOWLEDGEMENTS

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TALKSBAC: A PREDICTIVE ADAPTIVE CONVERSATION SYSTEM FOR NON-FLUENT DYSPHASICS.

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Abstract

A communication system, called TalksBac, has been developed which predicts phrases, sentences and story texts for conversational use. The system has been designed to augment the communication of adults with non-fluent dysphasia. The retrieval system uses a dynamic semantic network to identify probable conversational items which relate to user-selected parameters.

Background

Dysphasia following stroke leaves people with expressive and/or receptive difficulties of varying degrees, affecting both spoken and written communication. Generally, traditional AAC intervention with this client group has been unsuccessful due to the high levels of linguistic ability required to use currently available systems [1].

Although word prediction is beneficial for people with learning, spelling and language problems, most phrase and sentence retrieval systems remain code-based [2]. Preliminary work with two dysphasic clients using a predictive communication system indicated that some clients can recognise and choose familiar words and/or phrases within a conversational setting [3, 4]. A novel story telling facility allows for the retrieval and narration of longer chunks of text [4, 5].

System Overview

TalksBac (Talking And Learning Knowledge System for Better Aphasic Communication), a computer based predictive communication system, has been designed to guide the dysphasic user through a series of parameter choices until a target sentence or story title is recognised.

The TalksBac software is designed to run on a portable version of the Apple Macintosh computer. The internal Speech Manager provides access to speech synthesis without the need for additional external hardware.

The software reduces the complexity of information retrieval by restricting the number of choices presented to the user at any one time. First the user is asked to select the person to whom they are talking from a list of probable names. The program then offers a list of topic items associated with the chosen person. Predicted sentences and story titles related to the current person and topic/s are presented for selection.

The number of parameter choices and conversational items can vary according to individual users e.g. predictions can be presented one at a time or in a list of up to four. Selected sentences are spoken immediately whereas the selection of a narrative results in the narrative text being displayed with an appropriate control panel. This control panel allows the user to control the rate of the story narration.

System Design

The system has three main aspects (fig 1): the user interface, the prediction engine which controls a semantic network and database, and the carer interface.

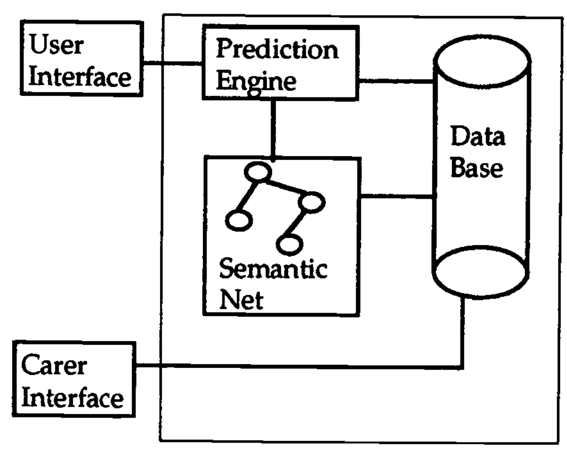

Fig 1: The System

The User Interface

The interface is divided into the user interface and the carer interface. The user interface allows the user to retrieve and "speak" pre-stored information, while the carer interface controls the input and management of the conversational data.

The user interacts with the interface by selecting labelled buttons with a built-in track ball. The number of buttons is minimised so that only the most probable options are offered. The options (i.e. the labels on the buttons) are compiled by the prediction engine.

Conventional storage and retrieval systems use static codes to access prestored information whereas the TalksBac system is adaptive. Choices made by the user activate the Prediction Engine which continually adapts a semantic network to reflect the user's conversational patterns. This reduces the need for users to remember what has been stored and where it is stored in the system. A specific conversational item may be accessed along a number of pathways.

The Prediction Engine

The prediction engine uses a semantic network to determine which topics/conversational items should be offered to the user. Conversational items in the database (phrases, sentences and story titles) are linked to one or more topic words. Each discrete topic word is represented in the network as a node (e.g. Canada and skiing in fig. 2). People are treated as topic words, but are tagged as being people. Topic nodes are connected alphabetically for direct retrieval. Nodes are also connected by weighted links which indicate the degree of association between topic words (e.g. 0.5 between Canada and skiing). These weights change dynamically to reflect use of the system. In addition to the weighted links, each topic node has a list of database items (sentences and story titles) which have been associated with the topic word (e.g. numbers 1, 2 and 3 in fig. 2 represent items in the database).

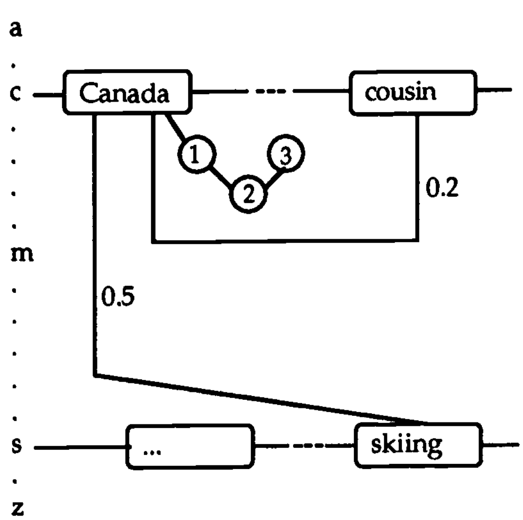

Fig. 2: Part of the semantic network.

The choice of topic parameters selected by the user has a two-fold purpose. First, it provides a template from which a list of probable items can be predicted; and second, the links between topic nodes are modified to reflect the user's choice. The prediction engine thus dynamically *alters* the form of the semantic network. This dynamic adaptation not only reacts to topic "closeness", but also reflects frequency and recency of use.

The Carer Interface

Entering new conversational information into the system is done via the carer interface due to the dysphasic users' expressive language difficulties. The carer can enter sentences, stories and people's names by simply typing in the required text at the appropriate prompts. The system parses sentences and story titles, ignoring all function words. The remaining words are used as associated topic words and the carer is given the opportunity to add or delete words from this list. The carer can also add associated words to people. A facility to delete or modify information is available.

Application and Evaluation

A small group of non-fluent dysphasic clients has been selected to take part in single case studies to evaluate the use of TalksBac as a conversation aid. A battery of formal tests has been administered to each client and will be used as baseline data. The tests will be repeated at the end of the project and will be used to indicate any change in the clients' comprehension and communicative abilities.

The first year of this two-year project has been spent developing the software. The second year will involve client use of individual systems. Clients and their carers have been trained to use the device and each client has been given a system to use for a year An analysis program allows the evaluation of prediction algorithm as well as identifying how often and with whom the system is used.

Acknowledgements

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EXTENDING THE FUNCTIONAL DAY FOR POWERED WHEELCHAIR BASED TECHNOLOGIES

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ABSTRACT

Technologies are increasingly being added to powered wheelchair platforms incorporating considerations for augmentative communication, writing aids (laptop computers) and environmental control. The self-contained rechargeable batteries in most add-on technologies will not provide a days operation for the more active client. Promotion of client independence and quality of life necessitates operation of assistive technologies for the full functional day. An efficient switching power supply was designed to convert the 24 volt wheelchair batteries into three separately adjustable DC output voltages to power wheelchair based technologies.

INTRODUCTION

Clients with more severe and complex disabilities are being integrated into school systems and communities, putting greater demands on the powered wheelchair platform. Wheelchair manufacturers have responded to this increasing demand by putting more sophisticated electronic control systems in place thereby facilitating client customization. Some manufacturers have provided features on their control systems in a generic manner that allows the client to use the driving control to perform other peripheral functions as may be necessary (ie. tilters, recliners).

Personal communication (whether face-to-face, voice or written output) and environmental control are examples of client needs frequently encountered in combination with powered wheelchairs and seating. Voice output devices have an operating time of 8-12 hours on a single charge, depending on the device. This would provide the user with operation over a school day, but not over a complete waking day. Laptop or notebook computers are used for all forms of personal communication in conjunction with the appropriate software and access method. These computers however only have sufficient battery life to operate for approximately 2-3 hours, depending on the model. This is not enough operating time for practical use in a school setting and makes the user dependent on others (and their skill level) to connect chargers during the day. The recharging process either requires the technology to be temporarily removed from the wheelchair or that the user be confined within a wire's length of the electrical outlet. This problem is compounded if more than one technology is mounted on the wheelchair and each requires charging.

The powered wheelchair usually has two 12 volt, 55 ampere-hour lead acid batteries connected in series to supply 24 volts to the control system and motors. Only extremely active wheelchair users require the full battery capacity to operate the wheelchair for a full waking day and manufacturers offer optionally larger battery capacities. Notebook computers (which are quite power hungry in comparison to AAC devices) require approximately 1% of the wheelchair's battery capacity per hour for full operation. That portion of the battery capacity not required for daily wheelchair operation can be converted into voltages to power other devices. Charging only the wheelchair batteries overnight will provide sufficient power to operate the wheelchair and all peripheral devices for the full day. An efficient and comprehensive method of power conversion was required to facilitate this.

DESIGN CRITERIA

Some computer notebook manufacturers have developed adaptors which allow the computer to be connected to the automotive cigarette lighter outlet. The outlet provides 12 volts DC and the adaptor converts this into the necessary voltages for the computer. Some rehabilitation centres use these adaptors on powered wheelchairs by connecting them to one of the two 12 volt batteries. This indeed does work but the uneven loading of the two batteries will considerably shorten the battery life. A wheelchair voltage converter should connect across both batteries and be protected from accidental connection in reverse polarity.

For the voltage converter to work with a number of different devices the outputs must be adjustable. If connection is being made to rechargeable batteries for extended periods of time, the voltage adjustment must be continuously variable versus step adjustable. These voltages are quite critical to prevent overcharging while maintaining a reasonably full charge on the battery pack. It should be noted that nickel cadmium batteries will develop a charge memory if maintained on a float charge. These batteries should be discharged on a regular basis (ie. once a week) to retain their capacity.

Anyone who has worked around wheelchairs will know that wires get pinched, cut and the plugs pulled off cables. The wheelchair batteries have sufficient power to cause personal injury and damage to electronics that are not short circuit protected. A fuse does not provided adequate protection for electronic components and does not reset itself when the overload is removed. The voltage converter needs to be short circuit and overload protected in a manner that will allow operation to resume when the problem condition has been removed.

Severe transients are produced across the battery terminals when the wheelchair is driven. Protection from these transients needs to be provided for the voltage converter and any devices it powers.

FEATURES

The Bloorview Battery Adaptor is a switching power supply which has three independent output channels with a common ground. The output ground is also common to the most negative terminal of the wheelchair battery series combination. Input power to the adaptor is supplied directly from the 24 volt wheelchair battery supply via a battery compartment fuse and power connector assembly. The adaptor is

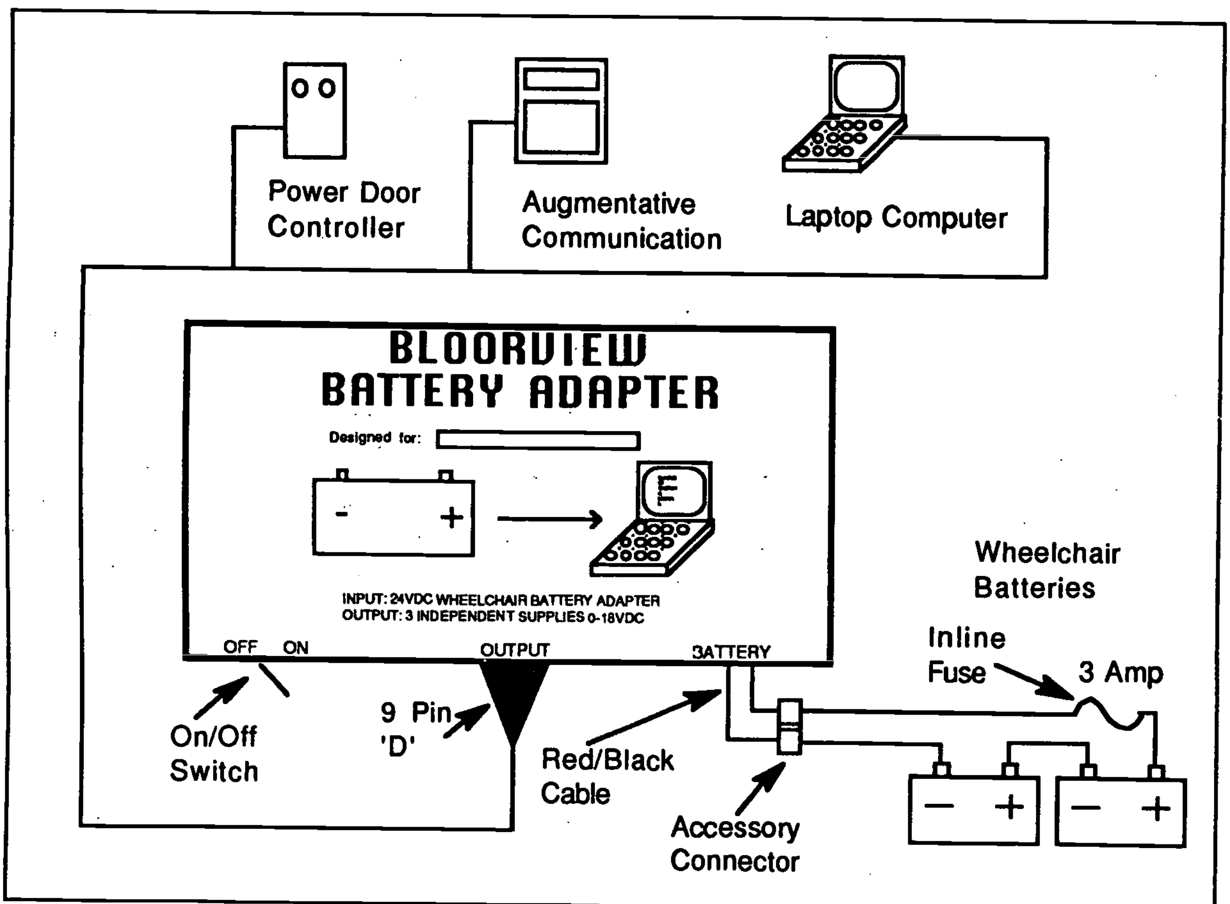

Figure 1: Typical Battery Adpator Configuration.

instantaneously protected from application of power in reverse polarity and will resume operation when the polarity has been corrected.

Each adaptor output is independently and continuously adjustable from 0 to 18 volts through a single turn potentiometer on the internal circuit board. Output connections are provided through a female 9-pin "D" panel connector for custom cabling and independent outputs are provided on three power connectors. Output regulation is 0.5% of output plus 0.1 volts. The standby input current is 40mA at 24 volts.

Each of the outputs are electronically short circuit protected and will resume normal operation when the shorting condition is removed. The power at each output is limited to 7 watts but outputs can be paralleled for higher power devices. Lower voltage devices can be supplied larger currents than can higher voltage devices according to, POWER = VOLTAGE x CURRENT.

Output transient protection is provided through an LC pi filter and computer grade switching capacitors. Input power is protected by an LC pi filter and transient protection circuitry.

The internal printed circuit board is self-contained and can be removed quickly from the chassis for servicing or board swapping.

DISCUSSION

The Bloorview Battery Adaptors have been supplied to several clients mostly for powering notebook computers and voice output devices. Some computers require multiple voltages and some require considerable power. Both of these factors reduce the number of other devices that can be operated since there are only three outputs and each output is limited to 7 watts. Environmental control applications included powering wireless transmitters such as those for powered door openers and remote access. Clients who require these transmitters are generally unable to independently change the replaceable batteries and discover that the battery is dead when the door no longer opens (this hopefully happens when the client is on the home side of the door).

The first Bloorview Battery Adaptor was installed 2 years ago. There have been no reports of clients running out of wheelchair battery power after the installation of the adaptor and computer system. Non-speaking clients can now communicate from breakfast through to the last snack at night with power to spare.

ACKNOWLEDGEMENT

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CANADA

A MORPHOLOGICALLY-BASED WORD PREDICTOR FOR SWEDISH

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ABSTRACT

In order to address the problems of undesired morphological forms in prediction lists, limited space available for lexicons, and limited space for predictions, a morphologically-based word predictor and accompanying base form lexicon have been developed for Swedish. Nouns, adjectives and verbs, which have multiple forms in Swedish, are chosen in a two-step process, by first choosing a base form, and then choosing the desired inflected form from an automatically generated list. An evaluation has been planned which will explore the possible benefits of this program for users with reading and writing difficulties by comparing texts written with and without this facility. Several unresolved questions regarding implementation and evaluation are discussed.

BACKGROUND

Several word prediction programs have been developed for Swedish and have been in use for a number of years [1,2,3]. The major word lists which accompany these programs have traditionally been frequency-ordered. The most recent evaluation of the Swedish word-prediction program Profet (English: Prophet), has shown improvements for some users in the areas of spelling, syntax, length of time in use before tiring and comprehension [4].

STATEMENT OF THE PROBLEM

An observation that has been made by program evaluators is that users can become frustrated when offered one or more undesired forms of a desired word in a prediction list. This situation occurs whenever more frequent forms exist, since the first few letters of the words in a noun or adjective declension or a verb conjugation are usually identical. Although word frequency is a major and powerful factor in successful word prediction, an informal test of the occurrence of less frequent forms provided an interesting result: 35% of all declinable/conjugable words in a chosen text did not appear in the first 5-element prediction list that contained a form of the word.

A companion problem is that in a frequency-ranked lexicon of a given size, all forms of all words do not appear, so that a desired form may not even appear in a later prediction list. This is particularly evident in a language such as Swedish in which a verb conjugation contains 20 forms (if you include the passive forms), an adjective declension, 7 forms and a noun declension, 8 forms. Including all forms in a lexicon would drastically reduce the semantic coverage through reduction in the number of unique root morphs.

Another possible constraint is the necessity to limit the number of entries in a prediction list. This constraint may occur because of visual or cognitive limitations, or because of limits on presentation area.

APPROACH

The solution which has been adopted in a version of Profet called Profend is to create a lexicon containing only base forms (verb infinitive, utrum nondeterminate adjective and nondeterminate, nonpossessive singular noun), and to develop an algorithm which allows the user to choose these content words in a two-step process. This approach presents the user with a list of words in consistent morphological form, and allows a given size lexicon to achieve significantly greater coverage.

IMPLEMENTATION

A lexicon was first constructed which is a combination of the 2,000 most frequent Swedish words [5] and a list of about 7,000 words in their base forms which Swedish students are expected to know upon graduation [6]. Any of the 2,000 most frequent words which did not occur in their base forms were then replaced by the base form. This lexicon was subsequently marked with codes corresponding to morphological classes (5 for verbs, 6 for adjectives and 11 for nouns). This categorization used the set of codes utilized in the Chalmers Lexicon [7].

A Morphologically-based Word predictor

A table was then constructed which contains entries consisting of a category code, a subcategorization code and a list of word endings. The subcategorization codes enumerated in the Chalmers Lexicon, are the actual letter strings which terminate a subset of words in the morphological category. To produce a desired morphological form, the algorithm accesses the base form, deletes the subcategorization code letter string from the base form and then affixes the desired word ending.

In the example below, the first line contains the base form for the word "flicka" (girl), the second line contains the category code "s1" (noun, category 1) and the subcategorization code "a." The third line first lists the inflections for indeterminate singular, determinate singular, indeterminate plural, and determinate plural, and then the inflections for the associated possessive forms. The indeterminate plural form, for example, would be constructed by removing the subcategorization code "a" from the base form to get the stem "flick" and then adding "or" to obtain "flickor."

Baseform: flicka
s1 a
a an or orna as ans ors ornas

It was necessary to provide a separate listing (file) of irregular verbs. Since the forms of many of these words differ from one another to such a great extent, this file contains whole words. An example is the verb "göra" (to do, to make). The list begins as follows: infinitive, imperative, present participle, present, simple past, past participle and verbal adjective (neutrum), verbal adjective (utrum),...

göra gör görande gör gjorde gjort gjord gjort...

When a user first sees the base form of a desired inflected word in a prediction list and chooses it, the program retrieves the word's morphological category from the main lexicon. Then, using the information in the table described above, the program generates all forms of the word and presents the new list to the user. Thus, the desired word is chosen in a two-step process. Of course, only one step is necessary if the word only has one form.

After a word has been completely specified and entered in the text, its base form is entered in the "subject lexicon" which contains words recently used as well as words used when previously writing about the current topic.

EVALUATION

A procedure has been designed in which the two programs Profet and Profend will be compared to determine user preference and potential benefit in writing tasks. The evaluation will be carried out with participation of two subjects who have reading and writing difficulties (with no motoric complication). A single-subject AB_1AB_2 design will be employed with replication across subjects [8]. The order of introduction of the programs (B_1, B_2) will be counterbalanced.

Baseline data of the subjects' writing abilities will be collected by asking them to copy a given text and to write a free text. They will be trained on Profet or Profend first, depending on the condition that they are assigned to. The program will be demonstrated and one of the investigators will work with the subjects until they can use the program independently. Subjects will be asked to use the program for 3 to 4 weeks, at the end of which they will be administered a probe test. After a break of one week, they will learn to use the other program and the above procedure will be followed. The probe tests will consist of copying, taking a dictation and writing free texts using Profet and Profend.

The texts will be analysed for morphological (and other) errors and ease of comprehension. The subjects will also be interviewed after each of the probe tests concerning there percieved effectivness and ease of use of the programs, and after both probe tests, concerning their preference.

DISCUSSION

There are several questions regarding implementation of Profend which are, as yet, unresolved. One question is concerned with whether all forms of a word should be presented. Verb passives, for example, are formed from the corresponding active form by affixing an "s." This addition could be provided for by showing a prediction list containing the single entry "s" after any verb form is chosen. No extra keystroke would be necessary if the passive form was not desired. Also, some conjugations and declensions have identical spellings for two forms. On the one hand, it seems unnecessary to list the same spelling twice in one prediction list, but on the other hand, it seems that listing forms in a consistent order would minimize the cognitive load of making the correct choice.

It would not be surprising if users found it counterintuitive to access extremely irregular verb forms from the verb's base form. Looking at the example of an irregular verb given above, one notes that it might be necessary to type "gö" to access the past participle "gjort." An alternative is to include all forms of irregular verbs in the main lexicon. However, one would want to present them to the user in a prediction list which contrasts in appearance or placement sufficiently from the normal prediction list so as not to lessen the advantage of otherwise consistent presentation.

Additionally, a procedure will need to be developed to allow users to specify a morphological category for new words before being assimilated into the main lexicon. Word class could be specified by choosing a set of words judged to be similar. After choice of word class, using the program's generation facility, it would be possible to present possible conjugations or declensions to the user for approval.

The need to limit presentation area in the switch access program SAW [9] has led to a request for our co-operation in providing a word-ending paradigm for the Swedish version of this system. With the lexicon and algorithm described above, the user, via a short list of baseform words, will be able to access all their morphological forms.

The results of the evaluation will probably depend on the specific reading and writing problems of the users. It is predicted that the two-stage word choice procedure provided in Profend, in which a first prediction list shows words which differ substantially from each other and a second prediction list highlights different grammatical forms of the same word, will aid some users in making morphologically correct choices. On the other hand, some users may not have the formal linguistic knowledge to be able to choose an inflected word using this two-step process. Linguistic competence will be particularly important if users are to choose inflected forms from base forms which differ radically in spelling. Recognition of related base forms may, however, be aided by the synthetic speech facility.

ACKNOWLEDGEMENT

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DEVELOPMENT, PROGRAMMING AND CONCEALMENT OF PRIVATE MESSAGES IN AAC SYSTEMS

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Abstract

People who rely on AAC need to express a full range of message types. The content and intended use of some messages is private and personal in nature. This paper describes an initial set of guidelines and programming strategies for working with people who use AAC to effectively develop and access messages of a private nature.

Background

Many individuals who rely on augmentative and alternative communication (AAC) do not program or arrange their own messages within AAC systems. The AAC user may be prohibited from doing so based upon barriers related to age, physical, cognitive, linguistic or literacy status, and/or lack of opportunity or related control exerted by others. As a result, messages of primary importance to the individual or specific preferred message wording may be overlooked by the assisting message/system programmer. The more personal, private, or intimate the nature of the message or sentiment, the greater the likelihood that it will not become part of the AAC system when an intermediary message constructor is necessary. The message constructor may feel intrusive, embarrassed, or reluctant to address the content inherent in the private messages of individuals who rely on AAC. Yet, these very messages may be of the utmost importance to the user in establishing and maintaining relationships with others and asserting individuality.

Banajee, Sands, and Schwery [1] postulate that communication devices "... are rejected secondary to their affective limitations." and note that "... constriction of affective expression is not only frustrating but limits the potential of the user to develop affectively attuned relationships." Working with AAC users to develop messages for meaningful communication of affect and a more sensitive approach to the process of programming were recommended by the authors. They conclude that acceptance and use of AAC devices is "...facilitated as affective attunement develops because the device is utilized for not only communicating for general purpose feeling and information but also for one's most private and significant feelings."

Beukelman and Mirenda [2] suggest that "... the ultimate goal of an AAC intervention is not to find a technological solution to the communication problem, but to enable the individual to efficiently and effectively engage in a variety of interactions." Four purposes are fulfilled in communication interactions according to Light [3]. These purposes are: 1) communication of needs/wants, 2) information transfer, 3) social closeness, and 4) social etiquette. Private messages may be required within any or all of these types of interactions but are weighted more heavily within the first three designations. Researchers have noted that relatively little attention has been devoted to strategies to enhance information transfer and social closeness interactions among people who use AAC [3,2]. Yet, as noted above, these types of interactions (especially social closeness) may be most important to AAC users and their significant others.

The precision of message content, facility of retrieval, and assurance of confidentiality are critical to construction and utilization of private messages. The goal of the assistive programmer then should not be to sensor, monitor, or repress such messages but rather to work with the AAC user (and others as appropriate) to develop effective strategies to support communication interactions of a private nature.

OBJECTIVE

In addition to daily messages intended for more public use, AAC users should be provided means to construct and/or program private messages which may be intended for use in very specific or limited circumstances but nevertheless be of critical importance. Independence for message programming and arrangement should be a priority goal in order to ensure that control and prioritization of messages will remain in the domain of the person who relies on AAC. However, in those situations where this is not possible on a short or long term basis, the support staff/significant others charged with the responsibility of programming vocabulary or constructing communication boards should: a) involve the AAC user in the selection, arrangement and content of messages to the greatest extent possible, b) present opportunities for the AAC user to address/select private messages for use in one or more communication forms, c) assure that the AAC user is able to select/appoint the person/s they would like to assist in programming private messages, d) assure that the methods for concealing and accessing private messages are acceptable to the AAC user, and e) keep all information regarding private messages confidential and inform others to support conscientious actions in relation to the same [4].

The objective of this paper is to provide strategies for identifying and incorporating private messages in AAC systems relative to the above guidelines and based upon clinical experiences.

Method/Approach

Private messages and conversations serve a variety of functions for everyone. Some of those functions include: a) development of personality, autonomy, and independence, b) establishing and maintaining a personal life and lifestyle, c) seeking direction, comfort, and support, d) transcending fear, grief, etc., e) maintaining or exerting personal control (questions, decisions, choices, etc.), f) manipulating outcomes, g) resolving issues, h) sharing feelings and thoughts, i) building relationships [4].

When working with individuals who do not independently generate or program novel messages, the assistive programmer may begin by sensitively introducing the subject of private messages and options for maintaining confidentiality. All agreements related to the programming of such messages should be documented, reviewed for final approval and kept on file. Potential topic categories for messages may then be presented auditorially or via a topic board. Some frequent categories for private messages include; legal matters, financial concerns, romantic partnerships, sexual matters, family issues, personal/emotional challenges, guardianship, abuse/neglect, discrimination, personal experiences, counseling dialogue, medical questions, and concerns regarding professionals and services. Before discussing the preferred content of messages within categories the individual who uses AAC should be provided the option of working with others to complete the programming process. It is possible that different preferred programmers will be identified for each category. In such cases, the primary programmer should attempt to instruct those people identified. Once messages and programmers have been indicated, strategies for incorporating the messages into AAC systems may be selected. Some potential options include:

1. Masking- For messages which must be explicitly displayed on static communication boards or device overlays, a simple covering of laminated, opaque paper may be used to mask the section of the board containing the messages. Velcro or tape tabs, metal or spiral rings, etc. may be used to secure the mask. If at all possible construction should allow for independent manipulation by the user. Instructions for use and/or a privacy warning may be placed on the superior surface of the mask.

2. Dedicated Boards/Overlays/Levels- One or more communication boards, overlays, or levels of high technology voice output memory may be dedicated for the purposes of private messages. If multiple overlays/boards are used by the individual but assistance is required in manipulating them, private message displays should be stored in a container separate from other displays and should be labeled with instructions for use, including <u>who</u> the user gives permission to manipulate them.

3. Alternative Coding- Individuals who use a particular encoding strategy (i.e. letter, icon, etc.) may find it preferable to use an alternative encoding strategy for private messages. For example, an individual who communicates general messages via letter or icon codes may use number codes for private messages only. The reference for these codes may be stored in a confidential file or committed to memory so that only the user and programmer are aware that they exist. Clinical experience with this method suggests that user recall for private message codes is particularly good.

4. Password Approach- This is one basic strategy which can be utilized to implement private messages on computer-based communication devices. In this approach the system operator needs to enter a specific sequence of keys, letters, or symbols, without prompting, in order to gain access to a set of private messages. If this is an intended feature of a given system or device, of course, it could be made available as part of the

firmware or operating system of the device. Otherwise, if a given device is sufficiently programmable or has adequate macro capabilities, it should be possible to devise a technique to implement this strategy for private messages. It can certainly be adapted to different vocabulary organization techniques. In a dynamic screen based device, it could be used to restrict access to hidden pages or levels of messages. In systems based on traditional orthography (e.g. abbreviation expansion), it would probably require specific firmware or operating system support to designate certain sets of encoded words and sentences as inaccessible until the password has been entered, since it would not be feasible to restrict the use of any of the 26 letters available as encoding elements. In icon-based encoding systems (e.g. semantic compaction), the larger number of encoding elements makes it possible to restrict access to one or more icons and use these in sequences for private messages.

5. Blank Key Approach- This approach, simpler but perhaps not as secure as the password approach, is based on simply hiding or not labeling one or more of the encoding elements or page selections needed to access private messages. This solution is simple enough that it should be possible to implement on just about any system, and places minimal demands on the system operator for additional key activation or remembering abstract codes. By including a blank, private message, the likelihood that some other unfamiliar individual would find any of these messages is greatly reduced. If the device being used provides support to prompt the system operator in entering valid code sequences (e.g. icon prediction), it may be desirable to circumvent or disable this feature for the hidden coding elements. However, the selection technique may depend on the use of this feature (predictive scanning) in which case it would need to be re-enabled to access the private messages, somewhat reducing the efficacy of this approach.

Discussion

The importance of including private messages in AAC systems should not be overlooked or minimized. Selecting, programming and accessing such messages presents a number of ethical and strategic challenges for people who rely on AAC, their assistive programmers and significant others. Programmers must present people who use AAC with comfortable opportunities to construct private messages, respect their wishes and guidelines in the development of private message strategies and procedures, secure confidentiality, and avoid the inclination to edit or otherwise unduly influence the development of such messages.

The authors have provided some basic, clinically tested guidelines for developing private messages and a set of suggested strategies for programming and concealing such messages in a variety of AAC systems. Further explanation and demonstration of these methods will be given in the presentation of the paper. Additional research and development, clinical testing, and consumer input are needed to increase user independence in creating and flexibly manipulating messages of a private nature.

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DESIGN STRATEGIES FOR AAC SOFTWARE, APPLIED TO THE BLISSPROCESSOR. DO THESE STRATEGIES COMPLY WITH THE USERS NEEDS?

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ABSTRACT

Communication has many appearances and is far from a static process. Disabled users who need tools for communication are putting a wide range of demands, not only of operational nature. Flexible designing strategies for the development of appropriate devices for AAC users are of crucial importance. In this paper a modular design approach and its application are verified against the primary goal: to meet user communication needs by AAC software.

BACKGROUND

In cooperation with the Bliss Communication Centre in Holland we have formulated design strategies for AAC software, focused on Bliss. These design strategies have been presented on the 3rd ICCHP conference, Vienna July 1992. Meanwhile, software has been developed for word processing Bliss documents as well as for speech generation, and different other Blissymbol related activities. That same spring, about 30 speech therapist conducted an intensive pilot study for about three months, using a prereleased version of the BlissProcessor. They sharpened and reformulated both user specific requirements as well as therapist related desires.
The software package has been completed in october 1992 and is now available in Dutch, English, German, and French languages; others are under preparation.
Since the introduction, dozens of bliss users and therapists are working with the BlissProcessor in many different ways, emphasising the changing demands for communication.

STATEMENT OF THE PROBLEM

In general, a communication tool can be described as an intermediate between a user and his or her surrounding world.

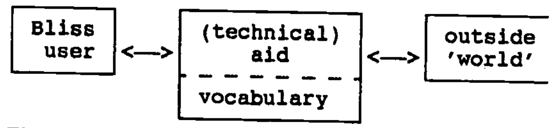


Figure 1. The basic communication tool.

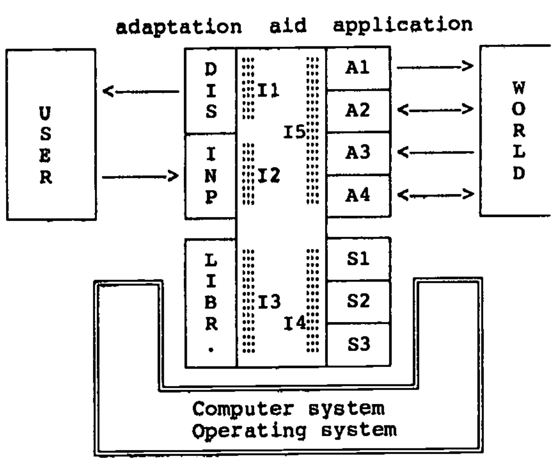
For many reasons, it is preferable that communication aids are universal applicable. Developers and suppliers prefer fewer and more versatile devices above numerous very specific aids. Therapist and rehabilitation centres hesitate to invest money and/or time in new devices and software if it can be used only occasionally.
But the group of AAC users who need such aids for communication is far from homogeneous. They differin motor abilities, vocabulary, cognitive level, visual abilities and last but not least, in social environment. As we have seen in the past years, the therapeutic and parental support plays a major roll in acceptance and optimisation.
The vocabulary of the user will likely grow or change gradually while the AAC user is maturing. In many cases, he or she will get some help to extend the symbol chart. While a communication device becomes personal and indispensable, it is unacceptable having the system to be returned to the manufacturer for a vocabulary upgrade. Therefor, a system should be flexible and easy to use.

DESIGN

In an early stage of the design, adaptation (how to operate and understand the tool) should be separated from the application (what the tool is used for). This separation has several advantages. First, it makes it easy to optimize an application (i.e. speech generation) to user specific needs, just by selecting a different input/display module and appropriate settings. Secondly, a modular approach can make the device multipurpose. Thirdly, future extensions can be added easily.

The decoupling of adaptation from application has another advantage. As it brings homogeneity towards the user, different kind of applications (training, speech or document processing) become easier to understand and operated.
While application developers don't have to focus on time consuming user specific adaptations, they will be motivated to create more and new facilities for communication.
If standard hardware and software is used wherever possible, it offers a high degree of future compatibility and will minimise costs.

It is clear that AAC software should cover several input strategies and devices, support different vocabularies, symbol sizing and background colouring to serve as a tool for communication, whether by speech, by paper or anything else. Such software should be modular as the need for adaptation and extension will never end, due to the nature of what we call "a living language".



DIS	= Display,	A1..A4	= Applications
INP	= Input module,	I1 .. I5	= Interfaces
LIBR	= Symbol library	S1..S3	= Supportmodules

An example could be:

A1 = Voice synthesizer	S1 = Bliss <--> Dutch
A2 = Text-processor	S2 = Blissymbolic printing
A3 = Training course	S3 = English <--> Bliss
A4 = Environment control	

Figure 2. A modular concept for AAC software.

In figure 2 the modular approach becomes visible. At the left side, the user interacts with its communication device by an optimal input/display interface. At the right, interaction with the outside world is fulfilled by speech, written texts, environment control or any other application. New features may be added easily as the developer of an application does not have to bother how the user interacts with its device. He only has to comply with the specifications of the interface (I5 in figure 2).

DEVELOPMENT

Input. All modules of the BlissProcessor can be operated by scanning, by pointing or by keyboard entry. Several scanning principles are supported, operated by one or two switches.
Pointing can be done by hardware devices such as mouse, joystick, multiswitch etc., all capable for four directions and one or two buttons indicating "Yes" or "No". Keyboard users may profit from many shortcuts and additional search functions.

Display. Apart form entry hardware, each user has his own vocabulary, symbol sizing, background colouring, command complexity level, selection strategy etc. A separate therapist/parent operated module enables modification of the vocabulary (chart) and all related settings.

Applications. Several program modules have been developed, both for the user and therapist. These are:

- BlissText, a word processor for Blissymbolic documents;
- BlissTalk, a speech generator optimised for speech reproduction and synthesis;
- BlissEditor, a module for the therapist to create new symbols fast and easily, and update them into the library;
- BlissChart, to modify user charts and user specific settings.

All program modules use the same symbol library and may invoke the same conversion routines to perform a communication task, such as printing facilities for blissymbols.
Towards the user it appears that each module is completely designed for his or her personal demands: operation, vocabulary and feedback by display.

System support. A PC, running MS-DOS is chosen. A reasonable priced widely available system. As the world market asks for smaller, portable robust computers, the AAC part of the society will only profit from it.

EVALUATION

In the beginning, therapist where a bit anxious to work with the BlissProcessor.
As many options were available and quite some speech therapist had no computer experience at all, they wondered how such AAC-software could be useful. But soon, they discovered several advantages of the computer-aided training. For example:

- A Bliss message becomes less volatile if presented the screen or on paper, offering facilities for training grammar.
- Therapist and parents can divide their attention to more than one Bliss user in the room without loss of communication.

Bliss users had less problems in acceptation, for them it was often the first time of their life they could make a letter on their own and send it to grandma or tell a story without the constant need of someone standing besides the wheelchair. Once the input device was optimized (critical important!) and once they were able to choose symbols from their her own vocabulary, many users tend to become addicted to the computer.
Both for teaching purposes and for writing purposes, the BlissProcessor is used intensively. Training material, poetry booklets are made and letters are mailed around.
By the time this article was written, speech generation was of second importance, due to the fact that only very few users had a portable computer. Speech synthesis was not fully implemented into the BlissProcessor until early 1994.

DISCUSSION

As many users of the BlissProcessor are using different computers at different places, they face some problems. Although they can easily take along their own bliss-chart on diskette, user specific symbols are not available everywhere.
Another problem arised as different therapists were modifying the symbol library at different computers, making it difficult to keep track on the home made symbols.

Apart from these initial strugglings, the modular design strategies have worked very well for the BlissProcessor. Therapists enjoy the possibilities of easy and fast making of new symbols, and the easiness of modifying the user's symbol charts and the printing facilities. From the users point of view, the document processor offers a complete new way for communication they had never dreamed of. A rugged portable with speech support is the next step to look for.

The flexibility of the multi-paged symbol charts offer the user access to an unlimited extendable vocabulary, independent of his physical limitations. Several users who have worked with about 400 symbols for many years are now demanding for more symbols. Until now, their physical limitation was limiting their vocabulary.
As the modular design has proposed, all people involved in the blissymbolic communication can get access to more or less specific parts of the AAC device. The system is easily adaptable and it can therefor be matched to user specific needs. It offers support for different communication tasks opening pathways for future extensions.

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TRANSLATION PROBLEMS OF TERSE MESSAGES IN VOICE OUTPUT COMMUNICATION AIDS

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ABSTRACT

Computer-based augmentative communication (AC) systems use terse messages to communicate functional aspects. Translations of such terse messages from one natural language to another produce problems. Systematic efforts used to produce terse prompts in one language have to be adapted when applied to another language. Felicitous results depend upon a thorough knowledge of the computer program and a knowledgeable native speaker of the target language.

BACKGROUND

Terse messages abound in life. They are found in public signs (STOP, YIELD, EXIT, etc.), personal memos (call doc for appt.), and computer program instructions (CUT, COPY, PASTE, etc.), among other places. These messages serve to reduce the amount of text of a longer message for space and time considerations. In one's native language, a reader of a terse message does not usually have many problems in deriving the original message. This paper will present some of the problems which have arisen in translating the operational systems of computers with terse messages into French, Spanish, Italian, German, and Swedish. Also, it will provide recommendations to others who are faced with the task of rendering computer systems comprehensible to speakers of other languages. Examples are provided from recent work done in translating the Prentke Romich Company Touch Talker™ (TT)/Light Talker™ (LT) operational systems.

STATEMENT OF THE PROBLEM

The messages relevant for the current discussion can be divided into separate groups: prompts (appearing in the display) and labels (on keys and appearing in the display). Labels in turn can be divided into functional and iconic categories. The prompts are limited by the number of characters available in the liquid crystal display. Both TT and LT displays allow 36 characters for prompt messages. The functional labels are limited three lines of eight characters by the amount of space on each key. The icon labels are allowed eight characters by the software. As with most other computer systems, the need for terseness is evident on the TT and LT.

Problems arise when such brief messages are translated from one language to another. Two characteristic problems are common. One is the creation of a new message in the target language which is substantially longer than the original message and does not fit into the allotted space. An example is END TO SAVE. The meaning of this statement is "select the END key to save a vocabulary item." The initial French translation became "APPUYER SUR FIN POUR SAUVEGARDER," a difference of 21 characters!

The second typical problem is the mistranslation of a message owing to the translator's misunderstanding of the original terse message. The basic cause of such misunderstandings is a lack of knowledge of the operation system on the part of the translator. A rather cryptic message from the TT/LT operation system, "FOR LOCKED MESSAGES; OK?" This function allows one to review messages whose icon sequences are in conflict with other icon sequences. The translator originally rendered the function as "EMPECHER L'ACCES AUX MESSAGES; OK?" This literally means "prevent message access." This translation actually reverses the meaning of the function. The problem here was the translator's lack of understanding of how the message fit into the system.

Thus three processes take place. The first can be viewed as expanding the terse message to a more expository version of itself. The second step is translating the expanded message. The third step is rendering the expanded, translated message terse in the target language.

The foregoing issues must be understood in the context of basic syntactic and semantic differences which exist between even closely related languages.

English has a special aptitude for terse messages because of its ability to use noun compounds. An example of this is the Italian name for the software called in English *Words Strategy*™. The Romance languages -- Italian, French, Spanish, Portuguese, Romanian, *etc.* do not permit nouns such as "word" to be used descriptively. One cannot say

"Parole Stratègia" in Italian. A correct rendering would have to be "La Strategia delle Parole."

Unfortunately, even this rendering does not mean the same as *Words Strategy*™ means in English. The separation of "Words" into a prepositional phrase substantially distorts the notion conveyed in English. The meaning in Italian is quite close to a direct translation of the Italian phrase back into English: The strategy of the words.

APPROACH

Although significant differences exist among languages, systematic efforts used to produce terse messages in one language can be adapted when applied to other languages. Several strategies based on linguistics and common sense have proven useful.

• *Choose the shortest possible message* A French version of Minspeak™ *Words Strategy*™ software uses an icon similar to an icon named CLIMB in the English version which depicts a pair of snow covered mountain tops. The French icon adds a minivan in front of the mountains. The two possible label names were MONTAGNE = "mountain" or CAMIONNETTE = "mini-van." The choice was obvious, MONTAGNE, not only because it was shorter than CAMIONNETTE but also because it only contains eight letters, the maximum allowed by the software. This permits the storage of the whole label rather than an abbreviation.

• *Appeal to established abbreviations* The burden on the user of learning a new code is eliminated when conventional abbreviations are used. Abbreviations like *ctrl*, *caps*, *tab*, *esc* can sometimes be used across languages or their equivalents can be sought in the target language. For example *ctrl* is understood in French, Italian, and Spanish.

• *Use acronyms* Acronyms may be more widely used in some non-English languages than they are in American English. Acronyms are particularly abundant in French, Italian, and German among others. Acronyms are especially useful for long titles EMOS = Enhanced Minspeak™ Operating System.

• *Use telegraphic language* The use of telegraphic language is universal on public signs. It is acceptable in computer prompts and labels even when grammatical rules of a given target language require the use of the prepositions, articles, conjunctions, *etc*. Telegraphic language is often the most natural solution for shortening long translations. Some examples with their French translations are the following: ESCAPE STORAGE = SORTIR MODE MEMOIRE *sortir de la mode mémoire*; VOCABULARY UNREADABLE (the vocabulary is unreadable) = VOCABULAIRE ILLISIBLE; THEME HAS BEEN CLEARED = THEME EFFACE *le thème a été effacé.*

• *Truncation* This is an intuitive process which involves chopping off the end of a word, while leaving just enough for recognition. Truncation is effective in a range of languages. It must be noted, however, that syllable divisions are different even in closely related languages. All of the translations mentioned in this paper employed saliency-based, word shortening extensively. Some French examples are: SECOND. (*secondaire*) = alternate overlay, CARACT. (*caractère*) = character, MAJUSC. (*majuscule*) = shift.

• *Suffix reduction* Though this process is similar to truncation, it appeals specifically to the ability of the operator to recognize the original suffix in an abbreviated form. Suffix reduction should be consistent throughout the system to lessen the burden on the user of learning to understand this strategy. Some examples are: SELECTN (*séléction*), FONCTN (*fonction*).

• *Vowel reduction* Vowels can be omitted from words, especially when they are found in unstressed position, without creating recognition problems. OVRLY= overlay is an example from English which exploits this strategy. Vowels play different roles in the various languages. Though most English vowels are reduced to schwas in actual pronunciation, this is not the case with vowels in Romance languages. Because of different linguistic rules for vowels and because of the intuitive nature of recognition strategies, caution needs to be exercised in employing this technique even with the collaboration of a knowledgeable native speaker.

An example of several strategies employed at once can be seen in the translation for the English prompt ONLY WORKS IN CUSTOM OVERLAY 128 MODE. The French translation of this prompt became "*fonctionne seulement en mode 128 acetate sur mesure..*" Although this message is relatively terse and difficult to interpret without a thorough knowledge of this system, it is still too long. The final prompt became: FCTNNE. SEUL. MODE 128 ACET. S.M. Suffix reduction, vowel omission, truncation, and telegraphic language were all employed to produce a prompt requiring 32 of the 36 characters available on the second line of the TT/LT liquid crystal display.

DISCUSSION

The approaches described were used extensively for translating functional and linguistic aspects for three different voice output communication aids (VOCA) into a series of European languages. It was found that principles used to produce terseness and comprehensibility in English could be adapted to the various targeted Indo-European languages. The extension of these principles to Hebrew, Arabic, Chinese, and Japanese is planned as a part of future developments.

The translation process is a team effort. The need for at least one computer-literate native speaker of the target language on the team should not be underestimated. Translators must be fully trained in the system to insure that all messages are understood and accurately translated. Problems arise from translators' lack of deep understanding of the operation of the computer. Further, the native speaker needs to have some knowledge of the general purposes of a VOCA in order to perceive whether a shortened message "works." Prompts used for data bases, word processing, *etc.* can be very different from those used for spontaneous, interactive language generation.

Perhaps as a last note, it may be best to regard translation not as translation but as recreating an operating system in another language. This will help to steer the team away from "rote" word for word translation which can lead to endless human factor problems.

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QUANTITATIVE INDICATORS OF COGNITIVE LOAD DURING USE OF A WORD PREDICTION SYSTEM

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Abstract
This study investigates the time cost associated with the cognitive processes performed during use of a word prediction system. Fourteen able-bodied and spinal cord injured subjects transcribed text with and without word prediction for seven test sessions. The extra time required to make word prediction selections, as well as times for keypress and list search actions, were measured as indicators of cognitive load. All subjects had slower keypress times during word prediction use, compared to letters-only typing, and spinal cord injured subjects had slower list search times than able-bodied subjects.

Background
The importance of cognitive load in determining user performance with word prediction systems is well-known. Task analyses have identified some of the component processes that may contribute to cognitive load, such as deciding when to search the prediction list and the visual search itself [1,2]. An important question continues to be how to quantify the effect and magnitude of this load. Measures of overall text generation rate provide a broad indication of the extent to which the cost in increased cognitive load counteracts the benefit of keystroke savings [3]. A more specific measure of cognitive load is extra selection time, defined as the additional time required to make each selection in a word prediction system relative to letter-by-letter typing. Extra selection time is assumed to be a direct reflection of the time spent on the additional cognitive processes.

Current knowledge about extra selection time is limited. A theoretical analysis has estimated extra selection time at 1.22 seconds, using results from information processing psychology [2]. The one reported empirical measurement is consistent with this, showing a range of 0.9 to 1.5 seconds, but measurements were made only for able-bodied individuals under a limited set of conditions [3].

Research Questions
This paper focuses on one aspect of an experiment in which the effects of a word prediction feature were studied with respect to overall text generation rate and cognitive load. While these two aspects are closely related, their differences warrant separate treatment. Specifically the goal of this study is to provide further understanding of the extra selection time associated with word prediction use, by measuring it under a broader set of usage conditions than have been studied previously. Additionally, we hope to measure cognitive load more precisely by separating the time for the primarily motor act of pressing a key from the primarily cognitive-perceptual act of searching the list. This is important in understanding the relative contribution of motor and cognitive factors to overall performance as well as a source of model parameters for future simulations of user performance.

Methods
Subjects. Fourteen subjects participated. All shared the following characteristics: at least some college-level education; high familiarity with the standard keyboard; no significant prior experience with word prediction; and no cognitive, perceptual, or linguistic impairments. Eight of the subjects were able-bodied, while the remaining six had spinal cord injuries at levels ranging from C4 - C6.

Interfaces. The "Letters-only" system involved letter-by-letter spelling on a standard computer keyboard, and the "Letters+WP" used single letter entry augmented by a word prediction feature. A six-word prediction list with a fixed word order was used, presented vertically in the top left corner of the screen. Able-bodied subjects used mouthstick typing, while subjects with spinal cord injuries used their usual method of keyboard access, which was mouthstick typing for two of the subjects and hand splint typing for the other four.

Experimental Design. An alternating treatments design was employed, in which subject performance with and without word prediction was recorded in each of seven test sessions. The keystroke savings provided by word prediction was fixed across Sessions 1 - 4 and varied in Sessions 5, 6, and 7. Three spinal cord injured and four able-bodied subjects were assigned to use one of two word prediction strategies to form four subject groups: SCI1, SCI2, AB1, and AB2.

Training. In the first part of training, subjects were instructed in the text transcription task, and then practiced using the Letters-only system for six blocks of text (four sentences each). The second part of training introduced subjects to the Letters+WP system and their assigned strategy for its use. The rule for Strategy 1 was to search the list before every selection. The rule for Strategy 2 was to choose the first two letters of a word without searching the list, then search the list before each subsequent selection. For both strategies, a search was not required when the list was empty. All subjects practiced using their strategy for four blocks of text (4 sentences each), which was sufficient for each to use the strategy correctly without prompting.

Testing. Each of the seven test sessions involved four sentences of warm-up using word prediction, an eight sentence test with word prediction, then a two sentence typing test. Text blocks were drawn from published typing tests [4] and revised to provide specific levels of keystroke savings. Sentences were presented singly on index cards which remained visible throughout transcription. Subjects had twenty seconds to read the sentence before an audio cue signalled them to begin transcription.

Data Collection. Subject behavior in each session was recorded on videotape. Additionally, all selected items were timed and stored by the software in real time. These raw data were filtered to remove events judged to be in any of the following three categories: text errors and error corrections; words not entered in a manner consistent with the assigned strategy; and "card reads", or times when the subject referred back to the text card during transcription, as identified through analysis of the videotape records.

Dependent Measures. Extra selection time was measured in each session and defined as the difference in selection times between the Letters+WP and Letters-only systems for that session. Selection time was defined as the total time required for a test divided by the number of selections (i.e., keystrokes) made during the test.

To measure cognitive load more precisely, the overall act of making a selection with Letters+WP was partitioned into the motor act of pressing the key and the cognitive-perceptual act of searching the word list. Each selection in a test was labelled according to whether it involved a keypress preceded by a list search or a keypress with no list search [5,6]. For example, when using Strategy 2, the first two letters of every word involved no list searches, so they were labelled as a keypress only. The keypress time (t_k) was then measured by averaging the times for all keypress-only selections. The list search time was calculated by subtracting one t_k from the time recorded for each list search-plus-keypress selection, then averaging the remaining times.

Statistical Analyses. Statistical differences in the dependent measures were determined using a repeated measures ANOVA technique. The between-subjects factors were strategy and presence/absence of spinal cord injury, and the within-subjects factors were system and session. Statistical significance within each test was judged at a familywise p-value of 0.05.

Results

Extra Selection Time. Figure 1 shows the extra selection times for the four subject groups. Spinal cord injured subjects had significantly larger extra selection times than able-bodied subjects, averaging 0.910 seconds compared to 0.413 seconds ($p < 0.0005$). For all subjects, extra selection time decreased significantly as subjects gained experience with the Letters+WP system ($p < 0.0005$). Subjects who used Strategy 2 generally had lower extra selection times, since fewer list searches were required, but the difference was not statistically significant.

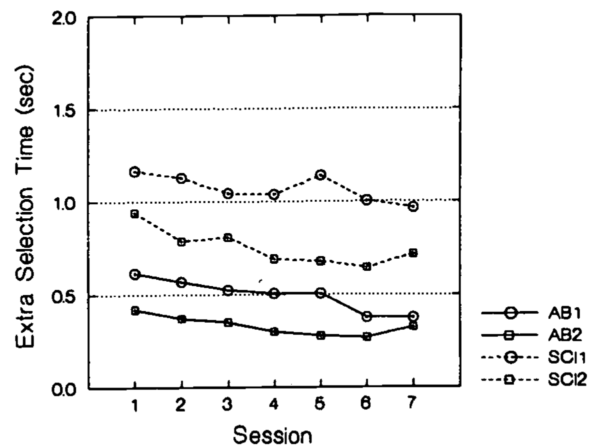

Fig. 1. Extra selection time with Letters+WP, relative to Letters-only.

Keypress-only Time. The average keypress times during use of Letters+WP are shown in Figure 2. There were no statistically significant differences between the groups, either on the basis of strategy or spinal cord injury. Session did have a significant effect ($p=0.001$), as keypress time improved an average of 17.7% from Session 1 to Session 7.

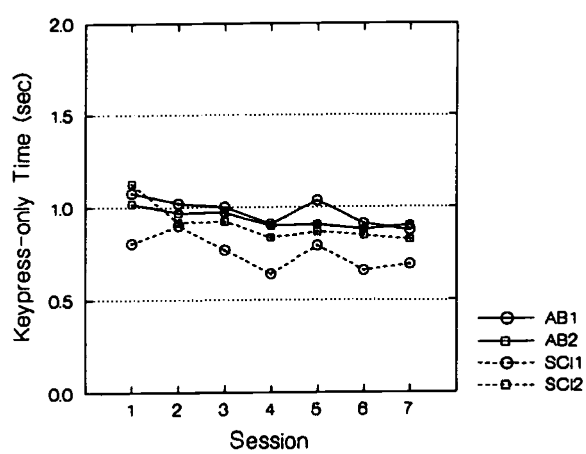

Fig 2. Keypress times during use of Letters+WP.

An unexpected result was that keypress times during use of Letters+WP were significantly slower than during Letters-only typing ($p < 0.0005$), with an average difference of 23% (170 msec). The keypress slow-down was more pronounced for subjects with spinal cord injuries than those without, with a slow-down of 48% (270 msec) for spinal cord injured subjects, and 10.8% (94 msec) for able-bodied subjects. However, this difference was not quite statistically significant.

List Search Time. Figure 3 shows the average list search times for the four subject groups. As with keypress time, strategy of use did not significantly affect list search time (p=0.058). Spinal cord injury, however, did have a significant effect ($p < 0.0005$); the list search times of subjects with SCI were an average of 96.4% (560 msec) slower than the able-bodied subjects. For able-bodied subjects, list search time improved an average of 27.3% (180 msec) from Session 1 to Session 7 (significant at $p < 0.0005$). For spinal cord injured subjects, however, list search time improved only 2.7% over these sessions, which was not significant (p=0.395).

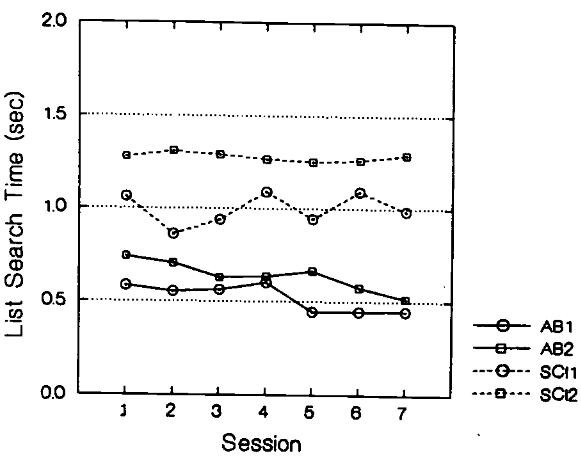

Fig 3. List search times during use of Letters+WP.

Discussion

These results suggest that using word prediction exacted a substantial cognitive cost for these subjects. Based on the extra selection time results, the execution of cognitive and perceptual processes comprised between 30% and 60% of the time spent using the Letters+WP system. The sources of this cognitive load and possible reasons for the differences seen between subject groups are discussed below.

List search time was a major contributor to cognitive load, measuring at least several hundred milliseconds for all subjects. However, it is unclear why the list search time for spinal cord injured subjects was so much larger than for able-bodied subjects. This may have been due to a difference in searching styles; perhaps the spinal cord injured subjects performed more thorough searches, while the able-bodied subjects used anticipation to skim the list on occasion. A second possibility stems from the fact that the technique used to measure list search time also captured the time for other processes, such as deciding whether to search or verifying accuracy of a selection, if and when they occurred. These processes contribute to the cognitive overhead involved in monitoring and guiding overall activity, and this overhead may have been greater for spinal cord injured subjects. This would not be that surprising, since they had much more prior experience under the Letters-only condition than the able-bodied subjects, which would increase the cognitive difficulty of switching to the Letters+WP system.

Cognitive overhead may also account for the result that keypress time was slower with the Letters+WP system. If keypress time had measured only the motor component of item selection, as intended, its duration should have been essentially the same with and without word prediction. That it was not suggests that cognitive overhead was present even during selections that did not involve a list search [2]. The relatively large keypress slow-down seen for spinal cord injured subjects provides further evidence of greater cognitive overhead for these subjects.

Certainly future work is necessary to address these unresolved issues and to examine cognitive load under different sets of conditions. This study provides a methodological starting point for future work as well as intriguing initial results. Continued progress toward understanding cognitive processes and their associated time costs is critical in order to clarify how cognitive load impacts overall user performance and, ultimately, to determine ways of reducing its effects.

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Predictive Letter Scanner for Augmentative Communication

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ABSTRACT

Communication rate remains a primary concern for people using AAC systems. In particular, single-switched scanning approaches, while useful for people with severe physical impairments, can be extremely slow. Letter prediction has been previously suggested as a rate enhancement technique. However, this technique is not widely available. This paper explores the possible reasons for this and suggests an alternative implementation that may promote letter prediction use with scanning devices.

INTRODUCTION

Currently, scanning devices are available that provide basic assistance to people with severe speech and physical limitations. Individuals who benefit from scanning based devices typically are unable to use other selection techniques such as direct selection (4). Unfortunately, the slow rate of communication achievable using a single switch scanning device can cause the user and listener a great deal of frustration.

The necessity of improving the single switch communication device becomes clear when comparing the communication rate of a non-disabled person to that of a person with a severe expressive communication disability. In normal speech a non-disabled person can communicate at a rate of 200 words per minute and type at approximately 55 words per minute (2). In contrast, individuals with disabilities typically achieve communication rates on the order of 2 to 10 words per minute (7). For alphabetic scanning systems, decreasing the average selection time per letter will effectively increase the rate of communication.

The goal of this research is to increase the communication rate achievable with a single switch scanning device while not requiring increased physical dexterity of the user. Letter prediction is a rate enhancement technique particularly useful in scanning-based systems. The implementation as explained in this paper provides a method of decreasing both the average number of scans and average number of selections per letter while minimizing the cognitive and perceptual burdens for the user.

BACKGROUND

Development of a rate enhancing technique for use with a single switch row-column scanner was initiated by the Biomedical Engineering Center at Tufts University (2). This research resulted in the development of the Tufts Interactive Communicator (TIC) and the Anticipatory TIC (ANTIC). The TIC ordered the display according to letter frequency in the English language. ANTIC expanded this concept by considering language redundancy to predict the most probable six letters based on the previous two letters typed. The six positions at the top-left of the display were dynamic and held the predicted letters. The remainder of the display consisted of the entire alphabet arranged according to frequency of occurrence.

Further exploration of predictive scanning schemes has been done at Northwestern University. The MicroDEC II used the statistical frequencies of language to improve text entry efficiency (8). The method of letter prediction used in the MicroDEC II utilized bigram frequency statistics to order the letters on the dynamic display according to their probability of following the previous character. The Portable Anticipatory Communication Aid (PACA), also developed at Northwestern University, utilized a dynamic display reordering scheme based on bigram frequencies as well (9).

While letter prediction offers theoretical rate enhancement as high as 40%, the technique has not enjoyed wide-spread use. One possible reason is that these systems made predictions by reorganizing the scanning matrix. This poses an additional cognitive perceptual burden on the user. In fact, experimental testing of the ANTIC showed that subjects experienced a great deal of mental exhaustion after 30 minutes of use. The decline in performance was attributed to the use of display reorganization to present predictions (5). In contrast, the system described in this paper implements letter prediction in a way that keeps the letter arrangement static.

IMPLEMENTATION

Like its predecessors, the *Predictive Letter Scanner* takes advantage of the statistical redundancy of the English language to determine predictions for the most probable character to follow the previous selection(s). The predictive scanner utilizes a static ordering of letters based on frequency of occurrence. Unlike the dynamic displays utilized in the ANTIC, MicroDEC II, and PACA, predicted items are scanned in their fixed positions. By keeping the vocabulary configuration fixed, some potential for user confusion is eliminated. Use of a static display also decreases the burden on the user of learning item positions on numerous scanner display configurations. Therefore, the visual search time as well as the number of missed letters is decreased. Finally, Barker's clinical observations support the use of a static display (1). She observed that experienced scanners look at the desired letter and select it once it is highlighted.

The *Predictive Letter Scanner* software is implemented using LASO (Library of Adaptable Software Objects), a C++ based software development library developed at the Applied Science and Engineering Laboratories (3). The current implementation runs on MS-DOS compatible computers. The letter prediction module is incorporated into a previously developed row-column scanner. The vocabulary set consists of the 26 alphabetic characters, space, punctuation, and control instructions. Single switch row-column scanning is done by highlighting each row in succession until the user selects a row with a switch closure. The highlighted marker then traverses the row until the user selects an item with a second switch closure.

Prediction Generation

A primary concern in developing an effective rate enhancement module is obtaining reliable predictions. If the desired letter is not among the predictions, the user must wait while each letter predicted is linearly scanned prior to beginning a row-column scan. For this reason as well as considering memory constraints, it is important to carefully choose the optimal number of predictions to present. Figure 2 shows the prediction reliability for the first six presented items.

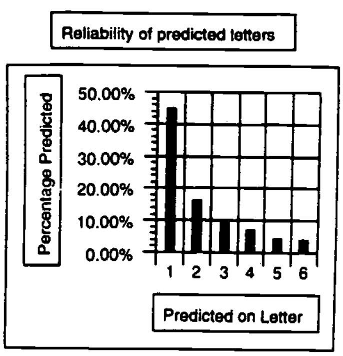

Figure 2: Frequency of correct prediction for the first six predicted letters.

Unlike its predecessors (which used bigram and trigram frequencies), the *Predictive Letter Scanner* uses up to three previously selected letters to predict and present the most probable next letter.[1] The Brown Corpus, a text consisting of over one-million words, was used to generate these frequencies.

Basing predictions on up to three previously selected vocabulary items increases the percentage of letters correctly predicted. In simulation experiments of prediction effectiveness using the Carterette Corpus, a text consisting of 77,800 words, the first letter predicted was correct 44.8% of the time.[2] Bigram prediction was correct only 27.9% of the time.

Basic Operation

Incorporating the prediction module into the row-column scanner involves instructing the basic scanner to communicate with the rate enhancement module. Each selection is reported to the prediction module as well as presented to the user via the screen. Predictions are indicated by highlighting each item in its fixed position. If none of these are the letter intended by the user, the system proceeds through a row-column scan.

The system is capable of predicting spaces and punctuation as well as characters. This is very useful when considering common word endings such as **ing**. In most instances, the vocabulary item that the user wants is a space. By considering this at the time of prediction generation the letter predictor will begin by presenting a space to the user. An additional feature is the prediction of a backspace. This occurs when less than three predictions are available to scan. The feature is included to alert the user of a potential misspelling or entry error and give immediate opportunity for correction.

The system allows the user to define the row-column scan rate. This allows users to adjust scan rate as they become comfortable with the vocabulary configuration. Because prediction scanning is not as systematic as row-column scanning, the reaction time may be slightly greater. Therefore, the system allows users to set a different scan rate for predictions.

During development a question was raised about the reliability of predicting the first letter of each word. The conclusion was to allow the user to decide whether predictions based on no previous letters would be helpful in enhancing the rate of communication. Additionally, the user may turn the prediction off.

Alternative Method

The *Predictive Letter Scanner* described above reduces scan steps and switch closures. An alternative method investigated presented the predictions first as a selectable group. In this case, the number of switch closures was the same as in simple row-column scanning, but the number of scan steps was reduced. Such a system would be beneficial to a person who has more controlled ability to operate a switch. When using Grouped Prediction, if the desired letter was not predicted the user could avoid unnecessary scanning by immediately beginning a row-column scan.

RESULTS

The *Predictive Letter Scanner* research studied the ability of letter prediction to provide an increase in the rate and ease of communication above that achievable with a single switch row-column scanner. Simulation experiments indicate that our goal of enhancing the rate of communication, while not requiring increased physical dexterity, was successfully reached.

Simulation Results

The Carterette Corpus was used in simulation experiments to determine the effectiveness of the prediction

1. The PACA system supplemented letter prediction with word prediction after the first two letters of the word were selected. Consequently, quadgrams would probably not have improved their prediction performance.

2. Predictions based on up to three characters entered in current word only.

module. Predictive systems which reorganize the visual interface are concerned only with decreasing the scanning actions needed to reach the desired selection. By linearly presenting each predicted item, the *Predictive Letter Scanner* can decrease the number of switch closures as well as the number of scan steps necessary.

Simulations compared the *Predictive Letter Scanner* with a single switch row-column scanner to determine its improvement in scan steps and switch closures. Table 1 presents the improvement results for prediction of all letters as well as linear prediction excluding the first letter. The results of grouped prediction indicate that a user might experience 40% rate enhancement.

Table 1: Predictive Letter Scanner Improvements

	Scan Step Improvement	Switch Closure Improvement
Linear Prediction (including first letter)	22.3%	34.9%
Linear Prediction (excluding first letter)	30.2%	31.3%
Grouped Prediction	40.1%	0%

RATE ENHANCEMENT METHODS

A number of methods have been presented to enhance the communication rate of an AAC row-column scanning device. The effectiveness of these methods was measured by considering the letters per minute improvement using the simulation results compiled from the Carterette Corpus. Calculations were done by holding the scan rate constant and varying the switch closure time. The results show a correlation between the Grouped Prediction rate enhancement technique and the time taken to make a selection. The Linear prediction methods are much less effected by the variation of selection time. In fact, as selection time increases the benefit of using a Linear prediction scan rises.

The theoretical results indicate that if it were possible to determine the user switch closure time the method providing the best rate enhancement could be used. Results indicate that all methods produce significant savings in time and effort. The method that is best depends on the user's switch closure time. Determining the switch closure time may prove to be a difficult task, therefore, it is expected that the most widely used method will be linear prediction without prediction of the first letter of each word. The improvement of this method remains relatively constant as the switch closure time varies making it attractive both to proficient switch users as well as users who require a greater switch closure time.

CONCLUSIONS

The incorporation of a letter prediction technique into a single switch row-column scanner is effective in its goal of increasing the rate of communication while not requiring additional motor capabilities of the user. Future enhancements of the system include speech output and continued investigation of additional selection techniques. In addition, experiments with subjects will be conducted to estimate the rate enhancement that can be expected in practical use.

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COMMUNICATION INTERACTION INVOLVING A YOUNG AUGMENTATIVE COMMUNICATION DEVICE USER AND HER PARTNERS

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ABSTRACT

The purpose of this study was to describe the communication patterns of one augmentative communication device user and her family partners as they interacted with one another.

Ethnographic techniques were employed to capture the verbal and nonverbal behaviors. Microanalysis of the participants' communication behaviors during various events indicated that each partner demonstrated a variety of partner characteristics. The results of this study show that when communication behaviors are analyzed within natural contexts for an extended period of time, family partners demonstrate a variety of communication attitudes, functions, styles, and intents. This model of Partner Characteristics can be used to yield a more accurate picture of the augmentative communication users communication abilities.

BACKGROUND

This study investigated the partner characteristics, conversational functions and styles, and communication intents of three partners interacting with an augmentative communication device user, and how these factors affected interaction. While the partner's characteristics were the focus of the study, the augmentative communication user's contributions and how they affected the partner interaction were included in the analysis.

OBJECTIVE

Since this study was motivated by the assumption that augmentative and alternative communication users are active communicators and are able to convey a variety of communication functions and intents, the following research questions were fomulated to guide this study.

1.) What opportunities are provided for the augmentative communication user to interact with a variety of partners in a variety of settings?
2.) What partner characteristics are demonstrated by each of the participants in each of the interactions identified by this study?
3.) What constitutes the primary functions of each of the interactions identified by this study?
4.) What are the communication intents that make up the linguistic environment provided by each of the participants in each of the interactions identified in this study?

The primary subject of the study, Elizabeth, was 6 years of age. She attended regular kindergarten and received physical, occupational and speech therapy within her educational setting. Her primary diagnosis was cerebral palsy with a severe expressive language delay. Elizabeth frequently vocalized, spoke in one-word utterances, gestured, signed, and used her Touch Talker while playing and interacting with her family partners. Mother and Father share in the responsibility of Elizabeth's daily care, play, education, and programming of her Touch Talker. Elizabeth's sister, Samantha, was 9 years of age. Samantha interacted daily with Elizabeth.

APPROACH

The data were collected over a seven month period through recording extensive field notes, videotaping naturally occuring interactions, and informal interviews with the participants (5), (7), (8). The data were collected in a variety of locations including the home, the school, a hair salon, the park, and the market. Only the data collected in the home with Elizabeth's family members (Mom, Dad, and Samantha) were analyzed for this study. Three interactive episodes were chosen for in-depth study because they represented the various communication styles of each partner. A "Take Off" game (variation of Backgammon) interaction between Elizabeth and her father was considered to be representative of the father's communication styles of informing and directing. A bookreading episode with Elizabeth and her mother "A Car Trip for Mole and Mouse" represented the mother's communication styles of informing, initiating, and co-participating. A pretend play-grocery shopping episode with Elizabeth and her sister, Samantha, represented the sister's communication styles of directing and modeling. In each episode, Elizabeth's communication styles included co-participating and initiating.

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DISCUSSION

The data clearly illustrated that Elizabeth participated in a variety of activities with familiar partners, in a variety of communication contexts. Analysis of the field notes and videotaped data indicated the presence of three partner characteristics: sensitivity, responsivity, and consistency (9). Each participant adjusted and adapted their communicative behaviors to one another, thus providing a responsive communication environment across context. Nested in these partner characteristics were the partner's conversational functions of didactic talking, communication anteing, and communication terminating. The communication interaction consisted of communication styles and functions which shaped the partner's communication intents, which made up the linguistic communication environment, used in the interaction.

The overall results of this study contradict previous research. The literature review suggests that in those studies partners are controlling, dominant, and occupy the majority of the conversational space (2), (4). The past research also described augmentative communication users as being passive participants and not contributing to the social interaction (1), (3), (6). The results of this study showed that when communication behaviors are analyzed within natural contexts over an extended period of time, functions, styles, and intents. These results highlight that communication intents and styles are partner and context specific. Analysis in this study also revealed that Elizabeth was an active communicator during all activities with all partners. She also demonstrated the flexibility and adaptability necessary to actively participate in the communication episodes examined. In light of these research findings, this model of Partner Characteristics can be used to guide future research to see if more naturalistic studies will yield a more positive view of the communication abilities of augmentative communication users.

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DEVELOPING AAC SYSTEMS THAT MODEL INTELLIGENT PARTNER INTERACTIONS: METHODOLOGICAL CONSIDERATIONS

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ABSTRACT

Augmented conversations are interactive. In a pilot study, we analyzed the transcripts of students with cerebral palsy describing pictures to their therapists. Described herein are some of the patterns observed during these interactions, and how they may reflect more general features in augmented communication. We suggest that some of these patterns should be modelled within future intelligent AAC systems.

BACKGROUND

Some computer-based augmentative and alternative communication systems are able to utilize knowledge of syntax, semantics, and vocabulary in order to facilitate the production of complete and correct sentences. To date, a number of studies have discussed aspects of the conversational nature of augmented interactions, but little attention has been paid to how they might be integrated into the AAC system itself.

Conversation is often a cooperative, bi-directional, and multimodal process of constructing and exchanging information. In the context of AAC, a conversational partner often becomes actively involved in constructing the augmented speaker's message (1). The partner may ask questions, repeat part of the augmented speaker's utterance, or simply nod and smile in agreement. This feedback may in turn affect the message being produced by the augmented speaker.

Computer-based AAC systems currently "see" only the words the user selects. The less information the user provides as input, the less the likelihood of accurate output. Studies with manual AAC systems suggest, however, that other modes of communication may be preferred. For example, children with cerebral palsy chose to use vocalizations, gestures, or eye gaze as modes of communication far more often than their manual symbol boards in interactions with their mothers or their speech therapists (2).These alternate modes of communication may be critical to fully understand augmented interactions. Already, the use of gestural recognition is being considered for future AAC systems (3).

In order to develop truly intelligent AAC systems, we must understand and address such characteristics of conversational interactions between an AAC user and a partner.

STATEMENT OF THE PROBLEM

The goal is to design an augmentative communication system that provides common interactional features of a conversation between a person using a communication aid and a conversational partner.

The first step has been taken in defining criteria for such a system by analyzing the data from a pilot study, and identifying a number of patterns that occurred during the dyadic interactions.

APPROACH

Pilot Study. The pilot data was collected by transcribing videos originally recorded by van Balkom (4). Adolescent students with cerebral palsy described pictures in a children's book to their primary speech therapists, using their own manual symbol charts. Four such adolescent-therapist dyads were videotaped and analyzed.

Each student was instructed to describe the pictures as if telling a story to younger children. The therapist was instructed to repeat each word as it was selected by the student, paraphrase the sentence when it was completed, and then ask the student for confirmation that the paraphrased interpretation was correct. A single camera was used to videotape both the student and the therapist. Students took between 11 minutes and one hour to retell their stories.

Transcription system. In an effort to capture as much of the multimodal content of the interactions as possible, the following vocalizations and gestures by both students and therapists were recorded:

- vocal productions (both words and non-words)
- hand and arm gestures
  - pointing at the communication board
  - pointing at the storybook
  - pointing elsewhere
  - unsuccessful attempt to turn the page
  - successful attempt to turn the page
  - miscellaneous gesture
- facial expressions
  - smile

- miscellaneous facial expression
- head gestures
  - head nod
  - head shake
  - looking elsewhere (not at board, storybook, or therapist)
  - miscellaneous head gesture

Eye gaze was not recorded, because experimental conditions did not allow accurate judgment of eye gaze direction.

DISCUSSION

Initial analysis of the data has indicated several interesting features and patterns of interaction that will be investigated further. For the sake of discussion, these observations are grouped into several categories, none of which should be considered exhaustive.

Co-construction. One intriguing behavior observed was that the therapist often repeated a sequence of the student's selections before a sentence was completed. The form of this repetition can be described as a function of two dimensions: degree of incrementality, and degree of interpretation.

Table 1: Incrementality vs. Interpretation

	Student	Non-Incremental	Incremental
Non-Interpretative	*boy*	boy	boy
	girl	girl	boy girl
	walk	walk	boy girl walk
Interpretative	*boy*	a boy	a boy
	girl	a girl	a boy and a girl
	walk	walking	a boy and a girl are walking

To illustrate (Table 1), the student might select the symbols 'boy', 'girl', and 'walk'. The therapist would echo "boy" after the first word. With a non-incremental/non-interpretative strategy, the therapist might also simply echo "girl" after the second word. With an incremental/non-interpretative strategy, the therapist might say "boy girl". With an incremental/interpretative strategy, the therapist might say "boy and girl", or "the boy and the girl", or "they".

These strategies were not observed consistently: a single dyad might contain several strategies, or combinations of strategies. Interestingly, these strategies were observed despite the instructions that therapists should repeat the symbols only as they were selected, and interpret them only at the end of the sentence. This suggests that therapists found it natural to respond this way in the communicative situation.

Word Find. When the student was unable to find a desired word on the communication board, or did not know a word, several strategies were used. The student might select a similar or related word, or point at the storybook, or use gestures to express the idea. For example, to express the word for sweeping, students moved their hands in a sweeping motion. Strategies employed by the therapist included guessing at the elusive word, examining and describing the picture in the storybook, or asking the student to spell the word if it was known but did not appear on the communication board.

Conversational Repair. The student indicated that the therapist's interpretation was incorrect in a variety of ways, including head shakes, uttering "no", or pointing at "no" on the communication board. Occasionally students responded to and corrected their own errors after hearing the therapist say the word aloud. Therapists indicated an error or misunderstanding with a head shake or by saying "no" or "I don't understand".

When a student omitted an important word, the therapist sometimes paraphrased the sentence by substituting an indeterminate filler for the missing word. For example, a therapist paraphrased 'girl', 'make', 'in', and 'pan' as: "Girl makes something in the pan". In response, the student responded by selecting the appropriate word to take the place of "something".

Confirmation. Generally, students confirmed the therapist's paraphrase gesturally or vocally, but occasionally selected 'yes' on the communication board. Therapists used verbal acknowledgments, head nodding, and reiterations of the student's sentence to indicate their understanding and agreement.

Therapists inherently offered students the chance to confirm or object to their interpretation of each word when they echoed the word aloud immediately after the student selected it, as they had been instructed to do. As well, therapists frequently requested confirmation from the students explicitly, asking, for example, "Is this what you mean?" before or after paraphrasing a sentence.

Other. Therapists often gave encouragements, such as "You're doing an excellent job!" or "That's good", and directives, such as "Ok, we can go on" or "Let's start over here". In addition, therapists asked "Is there anything else?" or "Are you done with this picture?" at almost every picture. It was not always clear, however, whether the therapist was prompting the student to say more, or simply inquiring whether to turn the page. Some additional commentary by the therapist occurred due to external distractions.

FUTURE CONSIDERATIONS

Preliminary analysis has suggested a number of refinements to be considered in subsequent studies.

Data Collection. A second camera would allow direct observation of the symbols selected on the communication board. In addition, better sound and lighting quality would be helpful for the task of transcription.

The storybook should be positioned so that the therapist cannot see the pictures as the student is describing them. The knowledge available to the therapist would then be more similar to the knowledge available to an intelligent AAC system. In the pilot study, the storybook was often used as an "extension" of the communication board through pointing gestures. Also, several times the therapist appeared to use knowledge of the storybook to add information to the descriptions that the student had not communicated.

Design Criteria. In the pilot study, the therapist played a dual role as interpreter and listener. In order to separate these two roles, a third person, unfamiliar with the student, may act as the listener. The therapist would perform the role of an imaginary AAC device, freely interpreting the communication of the student and conveying it to the listener.

Also, the therapist would not be explicitly instructed to echo each selection and paraphrase at the end of a sentence. Instead, we are interested in the interactive dialogue that would occur naturally in this situation.

Finally, in future studies adult subjects may be used, as well as a variety of AAC devices (both electronic and manual). In addition, a more familiar environment (e.g., home) may be provided for data collection. This will help ensure the observation of natural interaction patterns.

CONCLUSIONS

Observations from this pilot study reflect the potential for discovering common dialogue features and patterns in the interactive communication that takes place between AAC users and their partners. Further studies will allow us to define these patterns more accurately and completely, forming the basis of a model that can be used in the development of future intelligent AAC systems.

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AAC-USER THERAPIST INTERACTIONS: PRELIMINARY LINGUISTIC OBSERVATIONS AND IMPLICATIONS FOR COMPANSION

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ABSTRACT

Intelligent AAC Systems attempt to provide a communication system that can interpret input from the user in much the same way a familiar listener would. The COMPANSION system is a research demonstration prototype which "interprets" compressed input given by a user of a word based system into a full grammatical sentence. In developing a usable system from the prototype the needs of the user must be specified in well-defined ways.

This paper reports some preliminary observations from an experiment in which word board users interact with their therapist to tell a story from a picture book. The analysis compares the therapist's output with what could be achieved by a system like COMPANSION and discusses the necessary functionality for a second generation prototype as well as some of the potential difficulties that will be faced.

BACKGROUND

In recent years, a number of AAC researchers have attempted to develop techniques and systems that translate symbol or word input into well formed sentences (1, 2, 3). Common to the various approaches is the ability to inflect words (e.g., verb conjugation) and to add function words (e.g., determiners).

In the COMPANSION technique, a primary emphasis was the inclusion of a sophisticated semantic knowledge base and numerically-based heuristics for reasoning about relative word roles (2, 4, 5). For example, the system might take a set of input such as: "<apple> <pear> <eat> <john>" and generate "An apple and a pear were eaten by John". Note that in order to generate such a sentence the machine had to recognize that 'apple' and 'pear' were the things being eaten (recognizing a conjoined theme), and that John was doing the eating. In addition, appropriate determiners (e.g., "a") were added (but not to proper nouns such as John), and the appropriate passive construction was used (requiring the past tense form of "be" and a past participle ending on the main verb) in order to maintain the input order used by the user.

The COMPANSION approach has been implemented as a Lisp-based demonstration running on a Sun Workstation. In developing a second generation prototype that will form the basis for a practical system, it is necessary to validate the inferencing methods previously used and to understand any additional needs for a future product. To accomplish this, we need a methodology for deciding the specific functionality needed. Ideally, we would like our system to act like a familiar human partner does. Thus, this paper attempts to uncover interaction patterns that occur between an AAC user and a listener with an emphasis on the types of linguistic transformations performed in translating word sequences to sentences.

METHOD

Pilot data was collected by transcribing videos originally recorded by van Balkom. Adolescent students with cerebral palsy described pictures in a children's book to their primary speech therapists, using their own manual symbol charts. Four such adolescent-therapist dyads were videotaped and analyzed.

Each student was instructed to describe the pictures as if telling a story to younger children. The therapist was instructed to repeat each word as it was selected by the student, paraphrase the sentence when it was completed, and then ask the student for confirmation that the paraphrased interpretation was correct. A single camera was used to videotape both the student and the therapist. Students took between 11 minutes and one hour to retell their stories.

RESULTS

Some Interactions Consistent with the COMPANSION Approach:

Standard Compansion: Some interactions with the therapist followed the "standard" operation of the compansion system.[1]

S: <girl> <make> <in> <pan> <egg> <breakfast>
T: Girl *will* make *the* egg*s* in *the* pan *for* breakfast.

Here the therapist has added *tense*, and *determiners*. In addition the *plural* form of "egg" was chosen. Though not indicated by the student, the plural form may have been chosen using default knowledge (that people generally eat multiple eggs for breakfast) or it

1. In this and subsequent examples "S" stands for the student input and "T" the therapist. Words/letters added by the therapist are in *italics*. Words of particular interest are in **bold**.

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may have been the result of extra-linguistic information (e.g., the picture being described at the time). Notice that the preposition *for* was also included in the expanded message. This addition required reasoning about the semantics of the input sequence. For example, breakfast was the "reason" for making the eggs and should be introduced with a *for* preposition.

Word Order Changes: An assumption of the COMPANSION system has been that the words will be given to the system in the same order that they should be output in a sentence. However, some of our analysis reveals that the therapist sometimes did not follow the word order initially given by the student. The above example falls into this category: the eggs and the pan have been switched in the therapist's output. Consider the following example:

S: <boy> <table> <dusting> <grandmom> <floor> <sweep>
T: Boy *is* **dusting** ***the* table** *and the* grandmom is **sweep*ing*** ***the* floor.**

Notice that in this instance the student is not following a standard subject-verb-object ordering of the words. The therapist changes the order to follow standard English word order (it is not obvious how to form an English sentence while keeping the word order given by the student).

Agent Inference: Another assumption of the COMPANSION system is that a user might omit an agent when referring to him/herself. An agent might also be omitted if it was obvious from context. This behavior was also found in our analysis. Because the story was about a boy and a girl, students sometimes did not specify an agent, yet it was inferred by the therapist:

S: <wash> <clothes>
T: ***They*** *are* wash*ing* clothes.

Verb Inference: Another assumption of the COMPANSION system is that the main verb may be left out in some situations (particularly when the main verb is either *have* or *be*). We have argued previously that a system must have the ability to reason about which verb is most appropriate in the given situation. Our default rule (i.e., if there is an animate agent and an inanimate object, then the verb *have* should be inferred) is consistent with examples found in the transcripts. Consider the following where both the agent ("they") and the verb ("have") have been inferred.

S: <toys>
T: ***They have*** toys.

Conjunctions: Students sometimes left out conjunctions in the pilot study:

S: <boy> <girl> <made> <bed> <up> <in> <morning>
T: *The* boy ***and the*** girl made up *the* bed in *the* morning.

The conjunction could involve the agent role (as above) or other semantic roles:

S: <mom> <help> <shirt> <shoes>
T: Mom*'s* help*ing with the* shirt ***and the*** shoes.

Omitted conjunctions were also observed at the sentence level:

S: <girl> <make> <bed>
<boy> <help> <girl> <bed>
T: *The* girl make*s up the* bed ***and the*** boy help*s the* girl *make up the* bed.

Possessives: The inference of when a conjunction is necessary is complicated by the need to correctly indicate possessive information. The following example contains an inferred possessive.

S: <boy> <girl> <girl> <clothes> <my> <mother>
T: ***They're*** giving **their** clothes *to* ***their*** mother.

This example is interesting in that it points out several of the difficulties inherent in inferring when a possessive is needed. Note above there was both a conjunction ("boy" and "girl" combined to "they") and two possessives. A possible possessive rule might require that if you want a possessive followed by a noun, just put the two items next to each other (e.g., <girl> <clothes> for "the girl's clothes"). Note here <girl> <clothes> was translated as "***their*** clothes" as if <girl> was now "standing for" the combined agent. However, this strategy was not followed for the second possessive (the strategy would have resulted in <girl> <mother> being used). Rather the student chose the first person possessive pronoun, "my", to indicate the recipient in the message.

It is not clear in the data how much of the therapist's interpretation were influenced by the picture book itself. Nonetheless, it raises important questions about how to determine when a possessive form is desired.

Some Interactions Beyond the Scope of the Current COMPANSION Approach:

Dropped Word (included in interpretation): In some instances the therapist did not include words given by the student in the interpretation even though they often contributed to the intended meaning. Consider:

S: <two> <table> <in> <table> <dining> <room>
T: *There were things on the* table in *the* dining room.

Notice that <table> occurs twice in the student's input, but only once in the interpretation. In some sense, the student's input is "linguistically" sound. He is saying two things about a table (a) there are two things on it, and (b) the table is in the dining room. If these two assertions were stated as two separate sentences, then "table" would occur twice. However, as a single sentence there is a way to combine the thoughts without repeating "table". Compare this example with the possessive case above for an illustration of the difficulty in distinguishing this case from that of a possessive.

Replacing a Word (not included in interpretation): In some instances the therapist ignored words selected by the student, even though there was no obvious indication from the student to ignore the word.

S: <girl> **<help>** <clothes> <up>
T: Girl clothes up.
She's ***hanging*** *the* clothes up.

Note that in the above example **<help>** does not occur in the output. The example also shows a case where a new verb has been inferred (probably from the extra-linguistic context).

More Complicated Verb Inference (Adding or Replacing a Word): In some instances the therapist inferred a verb which was not actually included in the input:

S: <boy> <girl> <up> <table> <for> <lunch>
T: ok. *They're setting* up *the* table for lunch.

Dropped Words (not contributing to meaning): In some instances the therapist dropped words from the interpretation:

S: <girl> <look> <at> <to> <boy>
T: *The* girl*'s* look*ing* at *the* boy.

DISCUSSION

Throughout the study, we observed that much of the communication between the student and the therapist was **not** done through the word board. Several of the students were quite apt at getting their meaning across by a combination of vocalizations, gesturing, and pointing (both at the picture book and around the room). Such multi-modal communication is beyond the ability of most AAC systems available today, but would be a fruitful area of future research. However, in developing systems, it is important to understand which of these interactions are critical to the message construction process (e.g., yes/no gestures to confirm or correct interpretations), and develop means to support them in the system's interface.

In the development of "intelligent" AAC systems, it is useful and appropriate to look at user-partner interactions as a source of input into the analysis and design process.The information obtained from such a methodology can provide guidance and justification for the development of system knowledge bases and inferencing mechanisms. We believe that grounding system design in actual human interactions will insure that systems developed will be relevant to the needs of individuals with disabilities.

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Changes in Interaction Among AAC Users and their High School Peers

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ABSTRACT
This study examined changes in peer communicative interactions for five adolescents who used various AAC systems. Five repeated single case designs were used to address the proposed questions: what interactive behaviors are demonstrated by high school AAC users and their peers, and what impact does peer education have on these interaction patterns? The goal of the intervention was to increase communicative behaviors by the AAC users and nondisabled peers during homeroom class periods by educating the nondisabled peers about communication. Four communicative behaviors were coded on-line by two investigators before and after a series of peer education discussions. Results indicated that various situational influences were associated with successful peer interactions, and that the effect of peer education alone on communicative behaviors was limited outside of these situations.

BACKGROUND
Augmentative and alternative communication (AAC) system users are at risk for restricted opportunity and practice of communicative interaction skills with nondisabled partners. Increased educational integration has not consistently resulted in more and/or better communication between AAC users and their age-matched partners (1,4,6). Given the changes in social interaction patterns that occur in adolescence and the impact of physical and cognitive disabilities on social and communicative experience (5), adolescents with severe disabilities would be expected to demonstrate particular difficulties in initiating and maintaining communicative interactions. Individual peer education has been a successful technique to increase interactions for young children (2,3). This study examined the impact of group peer instruction on communicative interactions for adolescent AAC users.

RESEARCH QUESTIONS
1. What are some of the characteristics of communication interaction among severely speech and cognitively impaired adolescents and their nondisabled peers?
2. Are there changes in the interaction behaviors of adolescent AAC users and their nondisabled high school peers following group education activities?

METHOD
Subjects
Subjects were five adolescents, 3 female and 2 male (15-20 years). All subjects were classified in school records as having severe physical and/or cognitive disabilities that required AAC intervention. Two subjects used electronic voice output devices as their primary communication mode, one used a combination of sign language, speech, and electronic device, and two used a combination of gestures, vocalizations, and picture selection. All subjects received intervention in the appropriate use of their systems throughout this study.

Procedure
This research consisted of five repeated single case designs. The overall goals of the project were to first describe and then increase communicative behaviors of the AAC users and nondisabled peers during 15 minute homeroom class periods by collecting baseline data and then educating the nondisabled peers about the subject's communication behaviors and needs. The education activities included discussions related to types of communicative behaviors, commonalities and differences in communication modes and techniques, and motivational factors for communication, and methods for improving communication. These activities were adaptated from peer education procedures described by Cassatt- James (2). Interactive behaviors were coded during three baseline sessions and three probe sessions within two weeks after intervention. Observations were also recorded in a setting in which no direct intervention occurred; for two subjects (Subjects JD and KS) this was another mainstreamed class and for the other three (Subjects SA, CB, and TR) this was an off-campus vocational setting.

Four types of interactive behaviors were coded on-line during classroom sessions: attention bids, communicative initiations, communicative responses, and functional interactive behaviors. Behaviors were coded for the subject, and for the teacher and classmates when their behaviors were directed towards the subject. Percent agreement on behavior identification experimental coding was 83-89% across subjects. Communicative behaviors were graphed by time for each subject and examined for systematic changes between baselines and probes

RESULTS

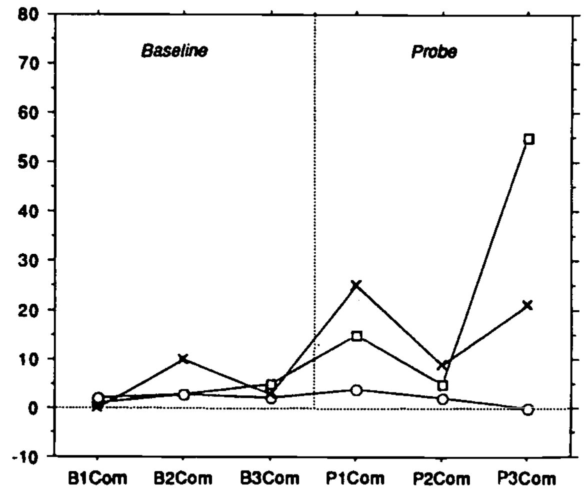
The total numbers of subject, peer, and teacher communicative behaviors observed in experimental sessions for each of the five subjects are displayed in Figure1. Only two subjects, TR and KS, showed increases in communicative behaviors between baseline and probe sessions. JD showed a slight decline in communicative behaviors, SA demonstrated consistently few behaviors, and CB demonstrated variable communicative behaviors throughout the experimental sessions. Therefore, while some subjects demonstrated behavior increases, the peer education intervention did not result in consistent changes in communicative behaviors by all AAC subjects. In general, communicative behaviors changed from baseline to probe sessions for some but not all of the subjects, peers, and teachers. While the intervention was designed to influence the likelihood of situations and attitudes conducive to interaction, any discussion of the independent influence of the intervention needs to be interpreted in light of other potential changes within the classroom itself. The circumstances under which changes in behavior did occur, and the role of the peer education in those changes will be discussed in the following section.

Figure 1: Total Communicative Behaviors During Coded Sessions for Five Subjects

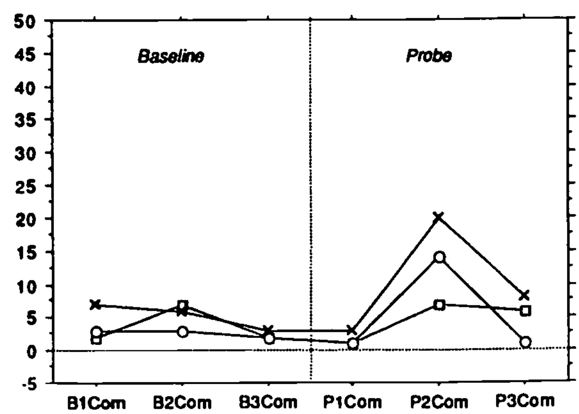
Figure Key:

- —□— *Peer*
- —○— *Teacher*
- —×— *Subject*

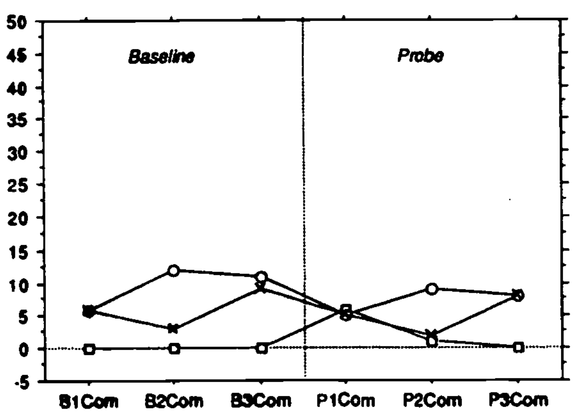
Communicative Behaviors in Homeroom Class for Subject TR



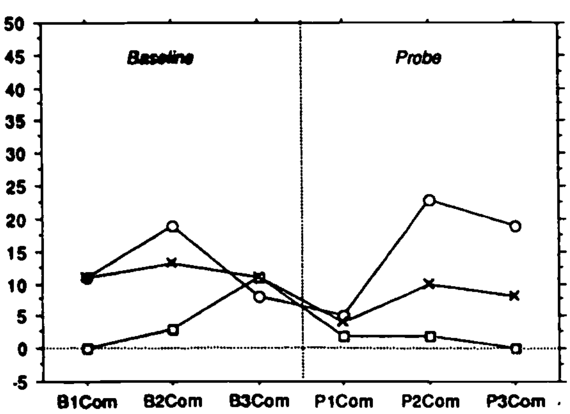
Communicative Behaviors in Homeroom Class for Subject KS



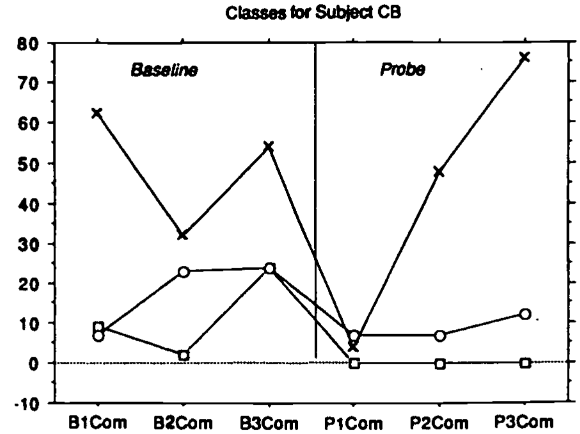
Communicative Behaviors in Homeroom Class for Subject SA



Communicative Behaviors in Homeroom Class for Subject JD



Communicative Behaviors in Homeroom Classes for Subject CB



DISCUSSION

Several methodological issues were likely to have contributed to these results. First, the time restrictions imposed by the homeroom class environment limited both the length of the interventions and the numbers of baseline and probe sessions. Also, a relatively brief intervention would be expected to have correspondingly subtle impact on the behaviors of the participants. On-line measurement techniques may not have captured the full range of behaviors occurring during the class.

Some of the most consistent features noted in class sessions with higher levels of communicative behaviors were situational factors that facilitated communicative clarity and opportunity. Factors that tended to co-occur with longer or more frequent peer interactions included the following:

Peer-appropriate group activities. Sessions with higher levels of student and peer communicative behaviors tended to be days on which group activities were conducted that involved multiple classmates. Sessions in which the subjects initiated activities that were less appropriate to peer interests were less successful at maintaining communicative interaction.

Communication routines. Greater initiation by subjects and responsiveness of peers and teachers was noted in circumstances with well-established communicative routines. Many of these routines involved greetings, standing jokes between classmates, or familiar conversation topics.

Object and environmental referents. Subjects were consistently more successful at obtaining and maintaining interactions with peers when those interactions related to some object or activity in the immediate environment, either available within the classroom or brought to class by the subjects. These environmental referents tended to facilitate three conversational functions: establishing joint context, increasing number/length of turns, and encouraging peer responses to subject behaviors or initiations.

Obligatory speaker turns. For some of the subjects, interaction was longer and more equally distributed between speakers if the activity prompted subject responses as well as peer responses. For instance, when JD was filling out a crossword puzzle with several peers, the situation necessitated a more equal exchange of communicative turns.

Practice of communication techniques in contexts. Given the relative unfamiliarity of the nondisabled peers with AAC techniques, successful interactions tended to involve messages that were directly transferrable to ongoing classroom activities. Subjects tended not to use the AAC devices in homeroom for messages that were frequently used in other settings, even if those messages were equally applicable to the homeroom.

In conclusion, brief peer education alone was an insufficient intervention for a "quick fix" solution to improve interaction. Peers are likely to need behavioral modeling within the context to provide consistent changes in communicative behaviors. However, there may be peers for whom education is appropriate and helpful, so we need to examine individual differences in responses in future studies. Also, students may experience changes in comfort level or attitude that are not immediately reflected in the observable behaviors coded in this study. Future research should incorporate a variety of methods to adapt communicative situations to foster interaction.

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COMMUNICATIVE EFFICACY OF COMPUTERIZED VIC AND NATURAL LANGUAGE

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ABSTRACT

A Communication Evaluation was carried out to determine whether NEWVIC, a version of computerized Visual Communication, was more effective than natural language for five individuals with severe, chronic aphasia. In receptive conditions, no group advantage for VIC over either auditory comprehension or written language comprehension was found. Two individuals demonstrated somewhat better success with natural language than with VIC, while one individual showed a small disadvantage for comprehension of written language as compared to comprehension of VIC or speech. One individual who participated in an expressive evaluation proved to be more successful with speech than VIC. These findings underline the importance of individual differences in designing alternative communication techniques for persons with severe aphasia.

BACKGROUND

VIC (VIsual Communication) (1, 2, 8) is an alternative communication technique for persons with severe chronic aphasia. Virtual cards, on which content and relational words are represented by pictures, are stored in piles according to their grammatical category, and are combined according to a rudimentary English-like syntax to produce VIC messages.

VIC differs from inert language boards, and from most augmentative systems for persons with neuromotor disabilities in one primary respect: as the user selects lexical items, s/he copies them to a message display area where they remain displayed and where their spatial order can be easily edited. In contrast, the user of a communication board has to preplan the temporal order of her/his words or symbols and retain a mental representation of their order, demands which are usually beyond the linguistic and memory capaabilities of persons with severe aphasia.

A number of people with severe expressive aphasia have demonstrated superior VIC comprehension and production in the laboratory, in comparison to natural language, and some of these individuals make use of VIC on a daily basis (e.g., (3)). However, the majority of VIC learners have not reached a level of competence adequate for functional communication. It has been argued that this result is unsurprising since individuals with aphasia exhibit, in their VIC performance, the same deficits that they exhibit in natural language (6).

RESEARCH QUESTION

The goal of this evaluation was to determine the relative effectiveness of the NEWVIC skills acquired by five participants in a study of the functional benefit of VIC compared to their natural language performance.

METHOD

Participants

Five individuals took part in this evaluation. All shared the diagnosis of severe nonfluent aphasia from single left hemisphere stroke, and had received intensive speech/language therapy, until discharged for lack of further progress. Scores on the Boston Naming Test and the test

	Gender	Handed.	DOB	DOI	VIC Begun
DB	F	R	3/29	3/89	3/92
JF	M	R	5/43	10/90	7/91
NG	M	AMBI.	11/33	1/90	9/91
FM	F	R	4/18	11/90	7/92
WS	M	R	8/36	4/89	10/91

Table 1: Participants

of Complex Ideational Material (CIM) from the Boston Diagnostic Aphasia Examination (BDAE) are offered in Table 2 as indicators of participants' approximate level of fluency and auditory comprehension at enrollment in the study. All were severely expressively impaired, and comprehension impairment ranged from severe to moderate.

	Speech Output (Boston Naming Test)	Auditory Comp. (CIM)
DB	0	7
JF	2	0
NG	0	4
FM	0	8
WS	5	9

Table 2: Speech and Comprehension

Task

In Receptive mode the task was picture selection. Eleven sets of four pictures each were constructed so that syntactic elements needed to be processed in order to make the correct selection. For example, the sentence for Set 6 indicated that either the dollar bill or the comb, was either next to or in, the purse. Conditions 1 and 4, contained VIC sentences, in Condition 2, the sentence was presented auditorily, and in Condition 3, printed words replaced the VIC symbols on the monitor. Syntactic constructions probed included transitives with two and three arguments, intransitives, prepositions, adjectives and coordination. No novel vocabulary was used.

In Expressive mode, the task was to produce a message describing the event or action shown in a picture which was presented along with the three others in its set. The participant was told that a receiver would try to identify the target picture from his message. The receiver stayed on the other side of a partition during VIC message production, then came over to the computer, read the message and made his choice. In the speech condition, the receiver listened from the other side of the partition, then came over to examine the pictures and select the one he thought he had heard described. In both cases, the participant decided when the response was complete. Only one of the participants, WS, was considered capable of carrying out the speech condition.

RESULTS

Participants were generally successful in carrying out the receptive task. Scores on all conditions averaged 8.4 out of a maximum of 11

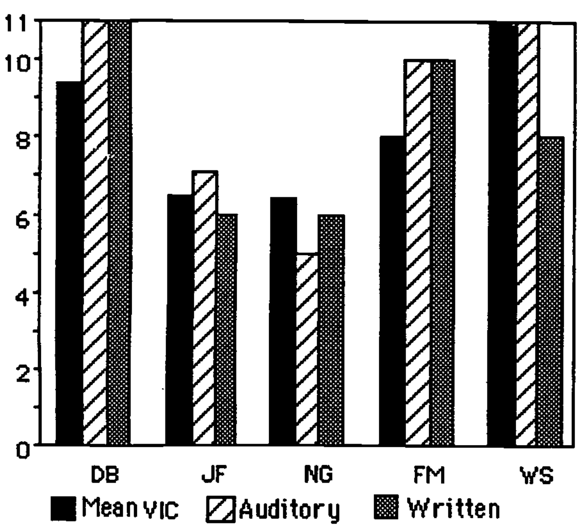

Figure 1. Receptive Communication

across individuals (compared to chance score of about 3), and individual averages ranged from 6 to 10.2. However, comparison of VIC scores to scores in either natural language modality fails to show any advantage for VIC across the group, or for any single individual. Mean VIC score (including the initial and final VIC condition, when applicable) was 8.3, compared to auditory and written comprehension means of 8.5 and 8.2. DB and FM scored perfect or near-perfect performance with natural language, but did more poorly with VIC. WS had more difficulty with wirtten language than with either VIC or spoken English.

Figure 2, below, presents the results for WS's receptive performance and his expressive performance with VIC and speech. In the expressive task, WS laboriously produced adequate spoken descriptions which resulted in correct picture choice by the naive receiver in all cases, while he succeeded in the VIC condition in only 4 of 6 cases.

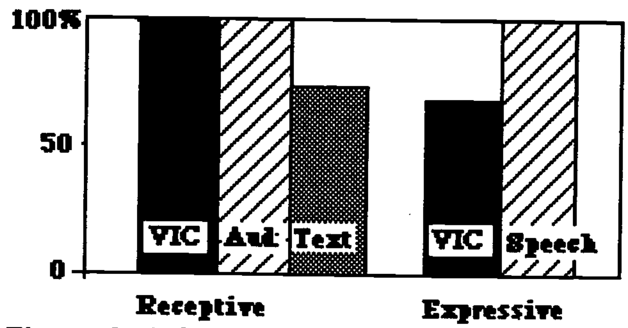

Figure 2. WS Communication Success

DISCUSSION

In NEWVIC training, cards displayed both picture symbols and text, and investigators named the objects and actions, so that approximately equivalent experience with speech, text and VIC as input were provided, although no explicit training was aimed at comprehension or production of natural language. This may have contributed to participants' approximately equivalent performance across the VIC and natural language modalities.

All participants were more than 6 months post infarct, and all but one were one or more years post by the start of NEWVIC training. Accordingly, there was little or no expectation of significant further recovery of language function. Probes of auditory comprehension and written language comprehension pre and post NEWVIC training showed no significant improvements in either modality. Written expression was not probed. Unexpectedly, speech fluency was found to improve for one individual. The number of relevant lexical items produced by WS in the "Cookie Theft" picture description task on the BDAE increased dramatically from 4 to 12. More strikingly, the number of

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structural items went from no phrases at all to two fully formed sentences. While this improvement followed NEWVIC training, the study did not provide means for determining whether the improvement could be attributed to the NEWVIC intervention.

If indeed VIC training has a positive effect on natural language recovery, it may be because VIC serves as a "mapping" therapy (7) by bridging the gap between conceptual representations of events and syntactic formulation. Individuals who benefit from VIC presumably have an abilities profile that includes deficits corresponding to the compensation that VIC provides, and preserved abilities which allow them to realize these gains in some modality, whether speech, written language, or VIC. In the case of EC, an individual with severe expressive aphasia and virtually no intentional speech, discussed elsewhere (3), training resulted in acquisition of an effective VIC communication channel, in contrast to absence of spoken or written expression. For WS, the VIC "mapping" orthosis, coupled with his residual fluency, may have benefited voluntary command of spoken language.

The claim that VIC communication is unsuccessful because VIC learners exhibit the same deficits in VIC as they do in natural language (6) assumes that VIC communication fails if the user does not command the rudimentary English-like syntax which VIC learners are taught. However, analyses of VIC performance both by successful VIC learners and by unsuccessful VIC learners (3, 4, 5) counter that assumption. Utilization of the meaning of syntax is in general the source of greatest difficulty for all VIC learners with severe aphasia, even those who go on to use VIC in daily interaction. The 'successful' VIC user, EC, referred to above, uses VIC as a language of 'nouns' which she groups together, and does not use the syntax in which she was trained for representing relational meaning (5). While she typically observes the default SVO (subject, verb, object) order, this order does not necessarily correspond to the meaning relations in her messages, since the first person-noun in her message is not necessarily the doer of the action represented by the following verb. Topic-comment may be a more accurate description of her VIC message organization than subject-verb. Investigation of spatial prepositions with several VIC learners has shown that a visual analog representation, in which pictorial symbols for objects are moved in order to depict their relations by physical analogy, is more successfully used, and perceived as easier and more natural by persons with severe aphasia, than are syntactic prepositional phrases. It may be that 'standard' VIC syntax is more appropriate as part of a language stimulation technique for persons with some prospect of return of expressive language, than as an alternative communication technique for individuals with severe and irremediable impairment. Further development and investigation of representational techniques will be required to make VIC an optimally useful communication tool for persons who have lost the capacity for natural language.

The cumulative results of studies of VIC performance by persons with severe aphasia indicates that syntax-based VIC is not necessarily the best system for all persons with severe chronic aphasia, and may be of limited benefit to many of these individuals. It is evident that individual profiles of preserved abilities and deficits must be characterized, and that the system itself, as well as the content and emphases of training, must be adapted to fit individual needs.

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Improved User Interface for Word Prediction

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ABSTRACT

Word prediction is a rate enhancement technique for communication and computer access systems. The typical user interface of word prediction require frequent view shifts between keyboard and display. A proposed integrated keyboard-display is developed and evaluated theoretically and empirically. The theoretical evaluation is not showing significant performance gain for the integrated display, and this result will be compared with the empirical evaluation.

BACKGROUND

Text based communication (AAC) systems require character input through an input device like a keyboard. To be effective, the input rate must be high enough to produce messages effectively. Many users of AAC devices do not manage to type characters fast enough to keep the conversation balanced. Different rate enhancement techniques have been developed, and one of them is word prediction.

A word prediction system is suggesting whole words to the user, based on the previously typed characters. The predictions may be based on language or word statistics, or on more elaborate language models.

The user interface is usually consisting of a window on the computer or AAC display showing the prediction list, and a set of function keys to select predicted words. In some systems the prediction list is following the cursor for character insertion (1). Word prediction on a PC is typically used in combination with a word processor.

In an earlier study (2) we have found that users of word prediction do a lot of view shifts between the keyboard and the display, and in this study we have focused on this user interface side of word prediction.

Horstmann & Levine (3) has introduced modelling techniques to AAC applications. The conclusion from their GOMS-modelling was that word prediction is not faster than simple character by character input. Newell & al. (4) has argued that GOMS-modelling of AAC-systems require models of disabled users, and should not be based on data from expert users.

RESEARCH QUESTION

The main research question in this study was how to improve the user interface in order to make word prediction more effective. The typical word prediction user is looking at the keyboard while typing. But to utilise the predicted words, he must look at the prediction list every time a new character is entered. The result is frequent shifts of view between keyboard and display. Our hypothesis was that a reduced need for these shifts would increase typing speed and decrease fatigue.

METHOD

A new design for a word prediction user interface was proposed. The design is based on integrating the prediction list display into the keyboard. The idea was to concentrate the items that the user have to focus on during typing and selecting predicted words. We found a keyboard (Comfort™ Keyboard System) that is divided into three parts: left hand keys, right hand keys and numeric keypad. We developed a prototype of a small prediction display based on a backlight LCD, capable of showing six lines of 8-10 mm high characters. A row of prediction selection keys was located at both sides of the display. A drawing of the display and parts of the keyboard is shown in Fig. 1.

The display has been evaluated through a GOMS-analysis (Goals, Operators, Methods and Selection rules) (5,6). A GOMS-model is a tool to simulate users behavoir when interacting with a computer system. It provides prediction of time to perform specified tasks.

Our GOMS-model is simulating three types of users: an inexperienced typist, a mouth stick user, and an experienced typist. The GOMS model can predict the time spent on the typing task, and we have compared the use of our integrated keyboard-display prototype with the standard configuration with the prediction list in a window on the computer display. The prerequisites for the GOMS analysis was:
- The words are typed according to word by word dictation.
- The intended word is shown in the prediction list when the two first characters are typed, and is the second word in the list.

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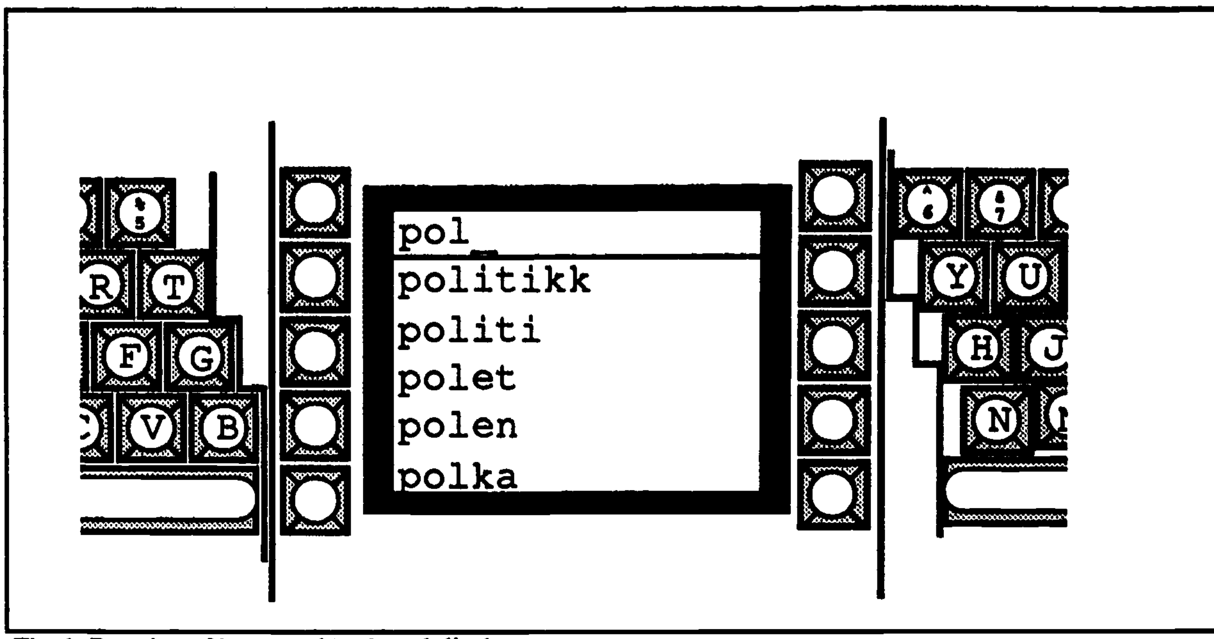

Fig. 1: Drawing of integrated keyboard-display.

- The mouth stick user is typing the characters one by one and is looking at the prediction list after each character is typed, and is using 2,4 sec on typing a character.

The prototype will be evaluated empirically during the spring of 1994. This evaluation will give results from actual use of the integrated keyboard-display. An alternating treatment single case design with a physically disabled subject, will be used. Typing speed, perceived benefits and any difficulties will be recorded. During the evaluation we will get information about the relative performance of the integrated keyboard-display compared with prediction list on the standard display.

RESULTS

The GOMS-model predicts correctly that the mouth stick user is the slower typist, and the expert is the faster. In other words, the model is sensitive to different user characteristics. Fig. 2 is showing the results for a mouth stick user without prediction, with predictions on the integrated keyboard-display and with prediction list on the ordinary display unit. From the GOMS model we get the predictions that word prediction is giving rate enhancement for longer words (more than 4 characters). The difference between the two display alternatives is not significant, according to the GOMS-model. The difference is only dependent on the different times for view shift between keyboard and display.

The empirical evaluation to be carried out during spring 1994, will give a possibility to validate the GOMS-results. If the user trials is giving the same results, we know that the GOMS-model is representing the user in a good way. If we get different results, we may be able to improve the GOMS-model with updated parameter values based on experimental data.

DISCUSSION

The GOMS-results does not support the hypothesis about view shifts being a major problem with word prediction systems. We do not know if the model is sensitive enough to this variable. We have only modelled a specific situation where word by word is typed according to dictation. By varying the different variables in the GOMS-model, we may be able to find out the sensitivity to the variation in user characteristics and scenarios of use.

The empirical evaluation will also give us a possibility to investigate this. We may also find other factors that are important when comparing the two alternatives. Fatigue may be such a factor.

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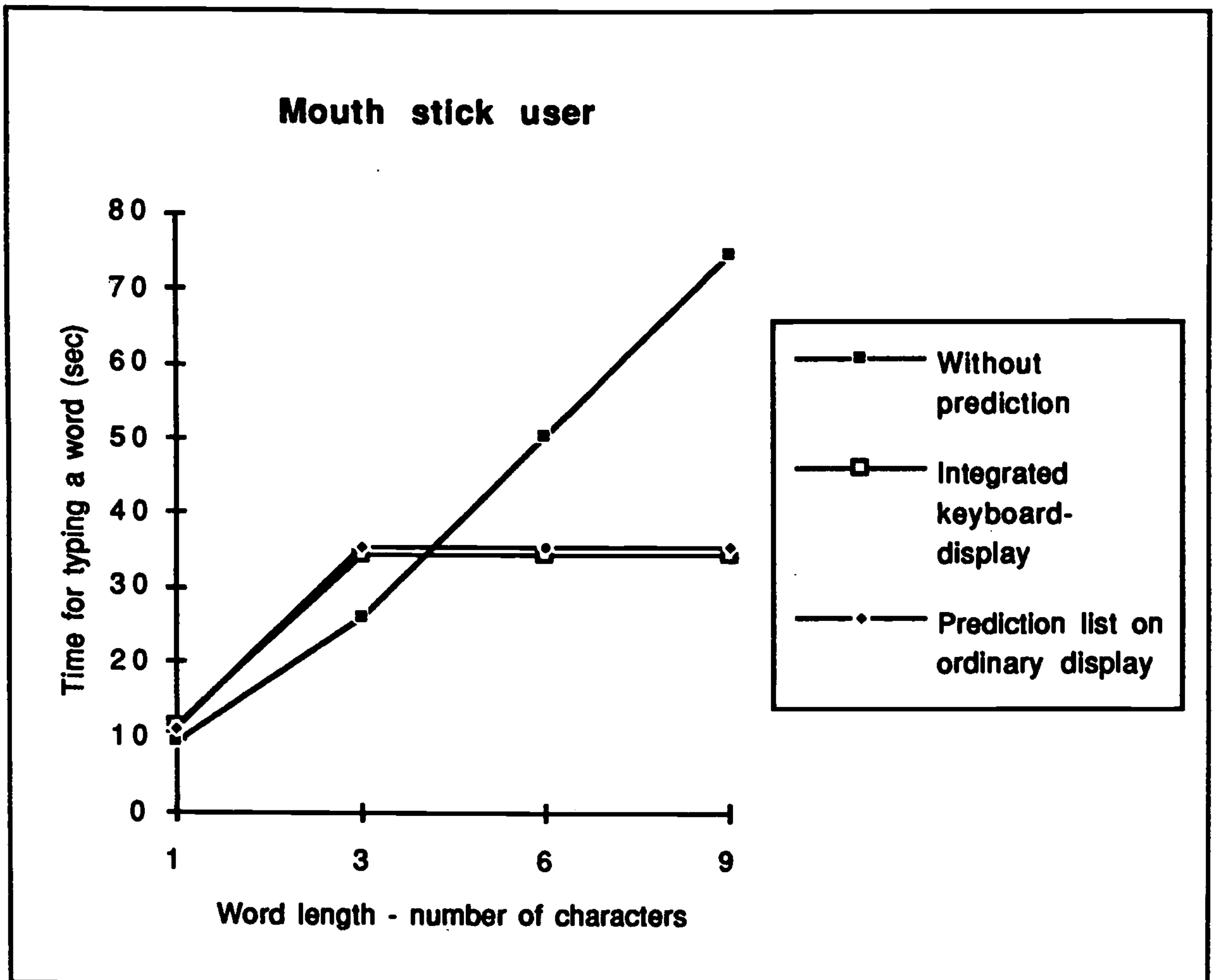

Fig. 2: GOMS-results for typing a word by a mouth-stick user

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SIG-04
Drooling

SWALLOW REMINDER, SALIVA PUMP AND CUP WITH FIXED DELIVERY VOLUME

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ABSTRACT

We present three devices designed to aid people with drooling or mouth control problems. The swallow reminder regularly emits a tone to remind the wearer to swallow. The saliva pump is used to suck excess saliva from the mouth. The cup delivers a fixed small volume of liquid on each tilting of the cup.

SWALLOW REMINDER

Background

Excessive drooling makes social contact difficult and special clothes are sometimes necessary. If someone can be encouraged to learn to swallow regularly they will be able to keep themselves dry without recourse to more invasive procedures. We have designed a device to assist in the accepted therapeutic practice of the use of body-worn swallow reminders.

The swallow reminder has been available for some time now (1), and to date 16 have been used. Clients are encouraged to swallow as the aid bleeps, in the hope that a swallowing reflex will develop (eg 2).

Design

The aid is constructed using two low voltage 555 timer ICs, a piezoelectric sounder and an SR44 1.5V battery. The battery gives over two months' continuous use. The surface mount circuit is arranged under the sounder, with the battery holder on the reverse side of the board. The overall size is 18mm high x 24mm diameter, shown in Fig.1. Decorative packaging of the device has been left to the user's choice. The time interval between bleeps can be adjusted from 15 to 120 seconds, with volume control also provided.

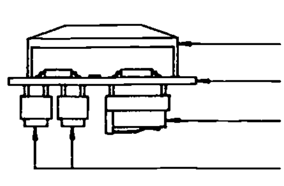

Fig. 1. Swallow reminder design

Evaluation

16 aids have been distributed with a variety of results. In each case, a speech therapist supervised the use of the aid and commented on the results.

Some clients are now dry and are making independent efforts to swallow and to hold their lower lip steady. Many clients, however, became accustomed to the tone emitted by the aid and in the absence of other reminders, and in one case of parent motivation, returned to their previous state. Before this accustomisation, a dramatic reduction of wetness was usually observed.

Discussion

New packaging for the aid is under consideration, and we are now supplying them with different tones to make accustomisation to the sound more difficult. We shall continue to make them available at cost price and pursue further publicity.

SALIVA PUMP

Background

People with bulbar palsy, as a result of motor neurone disease or other neurological diseases, find coping with excessive dribbling both problematic and distressing. These problems are obviously compounded when mixing socially. There is a need for a small discrete suction unit which can be used to draw excess saliva and mucus away from the mouth.

Design

Two prototype devices were constructed to investigate different approaches.

The first device was based around a small (0.4 atm) vacuum pump (ACL, Alton, UK). The pump applied a vacuum to a 150ml bottle which was mounted on the outside of a small box (65x120x40mm) which held the pump, batteries and other components. Three Nicad cells were used which could be recharged by a socket on the side of the box. We initially envisaged this unit being worn on a belt with a flexible tube to the mouth. This was later changed to its being used as a hand-held unit with a rigid tube which could be placed in the mouth.

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The other unit was based around a peristaltic pump unit in a box size 150x100x60mm. The fluid was collected in a 150ml bottle which located inside the box, but could be unscrewed from below to empty the contents. Power was from a single PP3 battery. The device had a shoulder strap. A flexible tube could be introduced into the mouth.

Evaluation

These devices were evaluated through discussion with therapists and short trials with potential users. It was soon clear that these devices did not provide the required solution, but provided a valuable starting point for discussion. The size was the main problem, as it was felt that a unit would need to be small enough to fit in either a pocket or handbag. One of the main constraints on size is the size of the fluid collecting bottle. The bottle used had excess capacity for the likely usage and so considerable saving of space could be made in this area.

A rigid tube was preferred, though this should have a soft end so as not to injure the inside of the mouth. The rate and power of suction was the other major area of concern, though it should be noted that during the trials the vacuum pump was found to be not working properly.

An area which needs to be carefully considered is that of the fluid reservoir, ease of cleaning and hygiene. It is vital that the fluid should easily be drained. It is also important that the user should be able to see how full the bottle is, though an audible warning when the bottle is full should also be incorporated. A particular problem with the vacuum unit is the need to reliably seal the bottle when it is screwed into the unit, as any air leaks reduce the effectiveness of the suction.

Development

The unit has been redesigned to meet the comments received during the evaluation. A vacuum unit is used which applies suction to a 30ml bottle. The bottle is housed within the box (75x100x40mm) which is cut away to allow the level of fluid to be observed and to allow the bottle to be readily unscrewed. A rigid tube is mounted on the outside of the box which folds away for carrying.

Discussion

We believe we have determined the appropriate specification for a saliva pump and have built a unit which meets the requirements. This will shortly be evaluated before more detailed development takes place.

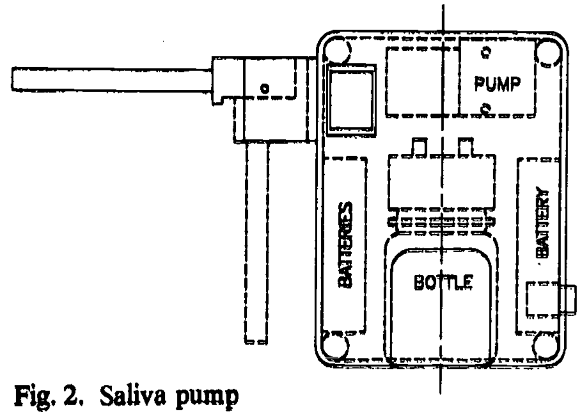

Fig. 2. Saliva pump

LIMITED VOLUME CUP

Background

Many people cannot drink from a standard cup for various reasons. This may be due to poor hand control or inability to swallow readily (dysphagia). Various cups are available with special handles and with lids which restrict the flow rate. These have two particular problems. The first is that they are unaesthetic and look more suited for babies than adults. Secondly it is more appropriate for many conditions to restrict the volume of fluid on each mouthful, rather than the rate of flow of fluid.

Design

The basic design uses an inner cup within an outer as illustrated. A reservoir is formed between the bottom of the inner cup and the outer. Fluid flows from the inner cup to the reservoir through a small hole. When the cup is brought to the mouth and tilted the fluid flows up a channel to the mouth. At the same time the level of the fluid falls below the hole so that no more fluid can flow into the reservoir.

A batch of five cups were made up to the above design, using a standard plastic picnic cup as the outer cup. This was an aesthetically attractive design. The inner cup was vacuum moulded and the cap was machined from solid.

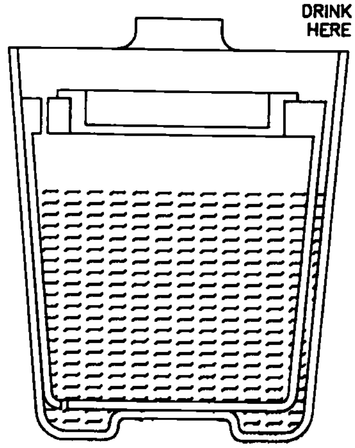

Fig. 3. Limited volume cup.

Evaluation

The general concept was praised and the cup was effective. There were however two comments which repeatedly came back. One was that the cup needed to be tilted a long way for the fluid to come out. This involved tilting the head back which exacerbated swallowing problems. Secondly the nose tended to come into contact with the cap of the inner cup. Some users would have preferred a two handled design.

Development

In order to decrease the amount which the cup needs to be tilted the angle of the cup should be as shallow as possible. The degree of shallowness is limited however by considerations of both stability and aesthetics. In order to reach the best compromise the shape of the cup became a tilted cone. Since no commercially available cup is available to this shape both the inner and outer have to be moulded using the vacuum forming process. This gives a less attractive finish to the cup. However possible volume production may allow injection moulding. This new design of cup is shortly to undergo evaluation.

Discussion

The concept of a limited volume cup has received wide interest, and evaluations have shown that the basic design is sound. A redesign to meet the detailed feedback is awaiting evaluation. If this is positive we hope to investigate commercial outlets for the design.

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SIG-05
Quantitative Functional Assessment

OBJECTIVE EVALUATION SCALES FOR THE QUANTITATIVE ASSESSMENT OF WALKING FUNCTION IN STROKE PATIENTS

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ABSTRACT

In this paper it is shown a quantitative method of diagnostic and prognostic evaluation of the hemiplegic patient in the acute phase, based on the combined application of the objective evaluation scales (neurologic, sensory/motor, functional), trying to establish a quantitative classification of the hemiplegic patients and to identify the more significant prognostic variables, in order to provide predictive elements of the recovery of the walking function.

BACKGROUND

The recovery of the walking function represents one of the main objectives of the rehabilitation treatment of stroke patients and, for this reason, a prognostic evaluation of such a recovery is of great interest. To this aim, it is very important that the prognostic methods should be, as possible, quantitative and repetible and this can be obtained if people acting in the rehabilitation field have at their disposal tools for a precise evaluation according to the different clinical "dimension" of disable subjects.

If the classification of impairments and disabilities has the previous mentioned carachteristics, the motor and functional evaluation of the patient provides several advantages to the clinician:

1. It allows to assign the patient to a predefined functional class on which it could be possible to plan a correct rehabilitative project, to choose realistic objectives for the treatment, to plan the recovery process and to quantify the results of the treatment.

2. It allows to obtain numeric data, necessary to perform quality controls and, consequently, to manage in a more accurate way the rehabilitative unit through information on the necessary resources in dependence of the degree of disability of the patients.

3. It allows to go in deep with the classification of motor and functional recovery, by taking into account many clinical variables, and by using numerical techniques to process them.

In literature, there are several approaches to the predictivity of the functional and walking outcomes, even if all of them can be ascribed to one of three different methodologies. Among these we have adopted the one that concerns the study of reliable prognostic criteria using objective evaluation scales applied to the quantification of impairments and disabilities. In this frame we have considered as particularly important the works of Wade and coll. [1] that have used the Barthel functional evaluation index with prognostic aims and Dettman and coll. [2] that using the Fugl-Meyer sensory/motor evaluation test were able to establish good prognostic correlations among the items evaluating the sitting and upright posture and the walking ability at the patient discharge.

METHOD

The study concerns 33 patients affected by stroke on an ischemic or emorrhagic vascular basis, sequentially admitted near the acute unit of the S.Anna Hospital and, successively, in the Unit for the Functional Recovery and Re-education of the S.Giorgio Hospital in Ferrara during the period from February 1991 to November 1992. All those patients that at the stroke onset presented secondary disabilities have been excluded from this study. The informed consensus to be submitted to the clinical evaluations, it has been obtained by all the patients .

All the patients have been evaluated by a physiatrist inside the 15th day from the stroke onset near the first recovery unit (neurological unit) and to each of them the following tests have been applied:

1. Fritz-Werner (FW) test modified by Mathew [3];

2. Fugl-Meyer (FM) test modified by Lindmark and Hamrin [4];

3. Barthel index (BI) modified by Wade [1];

All the patients have been submitted to rehabilitative treatment, either near the acute recovery units and in the rehabilitation unit.

At the discharge the walking function has been classified according to three functional levels (to which the labels C, A and N have been assigned): 1) Autonomous Walking, 2) Walking with Devices (ankle foot orthosis or crutch); 3) No Walking.

RESULTS

Figures 1 and 2 (5 and 6 classes respectively) represent the results of the cluster analysis connecting the FM and BI tests (y and x axis respectively). In Figure 1 two main aggregations can be individuated:

1) The first is characterised by a group of patients with low score in BI and high degree of variability of the FM score (c class):

2) The second (b class) and the third (a class) demonstrate less variability in FM with a substantial increase in the BI test score.

Class d is restricted to just one patient and it appears to be near to normal values. Class e, also restricted to just one patient (probably for the anomalous value in the FW test not showed in the bidimensional representation), is at an intermediate level between a and b classes.

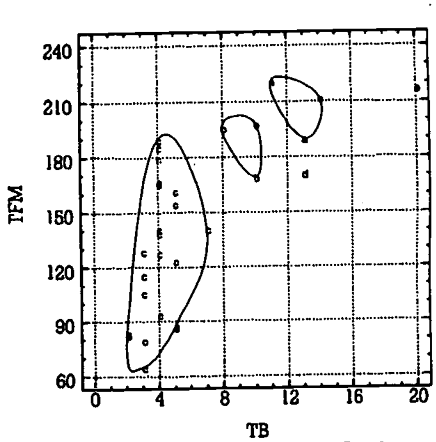

Figure 1 - Plot of the 5 classes obtained with the cluster algorithm on the Barthel and the Fugl-Meyer scores.

In Figure 2 a further application of the same algorithm on 6 classes allows to subdivide the c class in other two subclasses (j and k). In other terms the algorithm allows to identify two well distinct classes that are characterised by a low score in the BI index.

The classes obtained in this way have been compared with the outcome values for the walking ability, previously illustrated in the methods section; the results have been reported in Table 1 for the 5 classes case and in Table 2 for the 6 classes one.

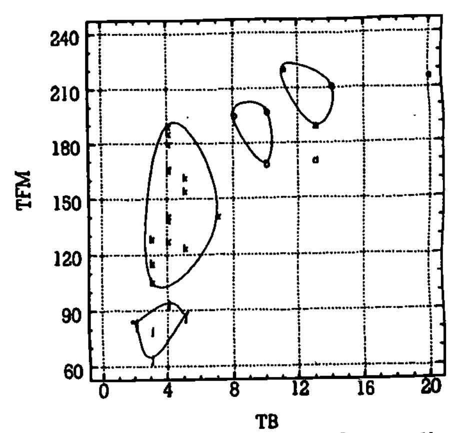

Figure 2 - Cluster algorithm applied on 6 classes.

	Autonomous Walking C	Walking with Aids A	No Walking N
Class a	2	1	0
Class b	3	0	0
Class c	9	6	10
Class d	1	0	0
Class e	1	0	0

Table 1 - Walking outcome frequencies respect to the 5 classes.

	Autonomous Walking C	Walking with Aids A	No Walking N
Class a	2	1	0
Class b	3	0	0
Class j	7	4	5
Class k	2	2	5
Class d	1	0	0
Class e	1	0	0

Table 2 - Walking outcome frequencies respect to the 6 classes.

Once it was established that by scores it is possible to obtain the clustering of data it was tried to identify the existence and the significance of the possible correlations. Table 3 shows the results of the Kruskal-Wallis test performed on the total scores of the three tests respect to the three levels of the walking outcome.

	FM	FW	BI
Group A	13.14	10.92	12.92
Group C	22.68	22.59	20.81
Group N	10.60	12.30	13.75
Level of Significance	4.007E-3	4.90E-3	0.081

Table 3 - Results of the application of the Kruskal-Wallis test to the total score of the three tests respect to the three walking levels.

The same kind of analysis has been repeated on the single items of FM: the most significant results in terms of predictivity have been obtained by the sections evaluating mobility (AMIP), balance (ABIP) and tactile sensibility of the inferior limb (ATSIP) (see Table 4).

	AMIP	ABIP	ATSIP
Group A	14.92	12.85	09.92
Group C	21.93	22.81	23.03
Group N	10.55	10.60	12.30
Level of Significance	0.011	2.97E-3	5.67E-4

Table 4 - Results of the application of the Kruskal-Wallis test to the mobility, balance and tactile sensibility items of the Fugl-Meyer test.

DISCUSSION

The clusters obtained by the total scores of the three tests, based only on the intrinsic property of the adopted metrics, are an interesting result from a methodological point of view, but by themself they would have a poor clinical applicability if are not compared with the reliable parameters of the rehabilitative process. As it can be noted from Table 1, for the classes a, b d and e which collect in all the 24.25% of the sample population, the probability to walk again at the discharge is very high (7 patients classified with Autonomous Walking and 1 patient with Walking with Devices), so they could represent a prognostic criteria for the clinician. Inside class c which collect the 74.75% of the sample population the situation is less clear: in fact 15 patients on 25 belong to the functional classes C or A and 10 belong to the N class. The further classification of the c class in the two subclasses j and k (16 and 9 patients respectively) is able to explain better the prognostic judgement. In fact in class j 11 patients on 16 belong to the C or A categories, that qualify walking, while in class k only 4 patients on 9 belong to such categories. So extimating from the observed frequencies the probability levels it could be possible to say that the probability for a patient of the class j to walk again is more then 1.5 times the probability of a patient of class k.
The maximum level of significance respect to the ranks created by the Kruskal-Wallis test was reached by the FM test. Also the FW test has obtained a good significance level but it appears less sensible to discriminate patients who will walk with aids by those who will not walk at all. The BI index applied in the first stage of the recovery has no predictive value so as the superior limb section score of FM.
In particular, looking at the single items of the Fugl-Meyer we can note that the mobility item even if didn't reach a high level of significance it is the best predictor of the future walking ability, while the balance item reached a very good level of significance with still good predictive capabilities. Even if the sample population in the future will be expanded to acquire more statistic soundness our results demonstrate the importance of a multi-factor approach to the study of this pathology aiming at the assessment of the correct rehabilitative treatment.

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PRELIMINARY DESIGN OF AN OPTIMIZED JOGGING PROSTHESIS

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ABSTRACT

Despite many amputees' interest to participate in athletic activities, no available lower-limb prosthesis allows an above-knee amputee to jog safely in a natural fashion. The objective is to design an above-knee prosthesis capable of replicating the dynamic motion of the normal lower extremity during jogging in sports activities. A mathematical model representing a novel design was developed to facilitate complete simulation of the stance and swing phases. The two main components were the Knee Control Unit (KCU) and the Swing Phase Mechanism (SPM). The KCU provided controlled knee flexion during stance, while absorbing the impact loads; it also generated some forward and vertical motion. The SPM permitted the amputee to swing the prosthetic leg freely during non-support periods. Information obtained from the simulation study was employed in the design of a prototype prosthesis. The unique features included a more natural, one-to-one stepping pattern, thus enabling an above-knee amputee to participate in sports that involved jogging.

BACKGROUND

Limitations of Existing Designs

Amputees who attempt to jog with their conventional prosthesis acquire an unorthodox and asymmetric gait pattern to vault over the straightened prosthetic leg; they take two short quick steps with the natural limb for each step on the prosthetic leg. Two steps on the non-amputated limb are required to provide sufficient time to swing the prosthesis through to complete extension prior to heel contact. Vaulting over the prosthetic leg reduces the drop in the stabilizing hip joint and increases pelvic rotation; these actions are great penalties as compared to normal motions. Knee flexion during stance is not attainable with conventional knee units and results in considerably higher reaction forces, which can cause degeneration of the residual hip joint and a shortened life for the prosthesis. Conventional swing control devices do not provide sufficient control during swing activities, as they are designed to operate over a range of walking speeds and do not cater to the increased knee angular velocities associated with jogging (3,5). Lastly, there are no known regulatory safety standards which dictate the acceptable design loads for lower extremity sports prostheses. Consequently, it is doubtful that conventional components can provide safe operation without any mechanical failure, if used for jogging purposes.

The Seattle foot and Flex foot were designed for active below-knee amputees and consisted of a plastic inner leaf spring that absorbed energy on heel strike and returned it in the form of lift in an attempt to emulate the toe-off thrust of a non-amputee jogger (2). However, personal comments from an above-knee amputee who tried jogging with the different feet indicated that they provided no appreciable aid in permitting a more natural jogging stride.

The Terry Fox Jogging prosthesis was designed to alleviate the asymmetric jogging pattern inherent with the use of conventional prostheses. The prosthesis was comprehensively assessed in the gait laboratory and was not found to be an optimal design (3). Nevertheless, the information gained from this study was deemed useful in the design of the proposed physiological prosthesis.

INTRODUCTION

Need

The number of young amputees in North America continues to grow, due to cancer and traumatic events. Many of these individuals were active prior to amputation and wish to continue an active sports life. Jogging, which is the basis for many sports, remains the most difficult activity to achieve and causes the most discomfort (1). Commercially available walking prostheses can not be easily adapted for jogging. Hence, there is a growing market for a sports-oriented prosthesis for above knee amputees that will allow a balanced, physiological prosthetic to natural leg jogging stride.

Objectives and Design Criteria

This paper presents the preliminary design of an above-knee prosthesis capable of reproducing the dynamic motion of the normal leg during jogging. The necessary design criteria were established from non-amputee jogging patterns (4). The design goals for the stance phase are to absorb the large ground reaction forces at heel contact, provide self stabilizing knee flexion, and generate some forward and vertical motion. The prosthesis should also provide reliable support during stance. To achieve these objectives, about 20° of knee flexion was desired at heel contact. Such controlled knee flexion lowers the center of mass of the body, thus eliminating the need to vault over the prosthesis. During the swing phase, the prosthesis must first be accelerated and then undergo controlled deceleration prior to heel contact. Lastly, some amount of knee flexion at the end of swing is necessary to stabilize the joint.

DESIGN ANALYSIS

Mathematical Description of Prosthesis

A mathematical model representing a novel design of a jogging prosthesis was developed to facilitate complete simulation of the prosthesis for both stance and swing phase operations. The components of the optimized jogging prosthesis are shown in figure 1(a). A conventional socket and prosthetic foot were incorporated into the design. The prosthesis was modeled as a three link system, as shown in figure 1(b). Link 1 represented the thigh and socket, and link 2 represented the shank tube and prosthetic foot. The Swing Phase Mechanism (SPM) was located in link 2 and consisted of two buffer springs fastened to the shank tube at the end-points of travel of the slider joint. The third link represented the Knee Control Unit (KCU) and consisted of a large compression spring enclosed at both ends by parallel plates, connected together by a shaft passing through the center of the spring. The position of the upper end plate was adjusted to create a preload force on the coil spring and served to regulate the onset of knee flexion during stance. Once the impact force exceeded the preload force the spring compressed, causing the knee to flex. Links 2 and 3 were coupled during the stance phase and decoupled during swing using a latching mechanism located inside the shank tube. The timing and triggering of this device was established from the kinematic analysis of non-amputee jogging patterns (5). The latching mechanism returned the knee to a flexed position prior to heel contact, which was beneficial in initiating absorption of the large reaction forces encountered at heel strike.

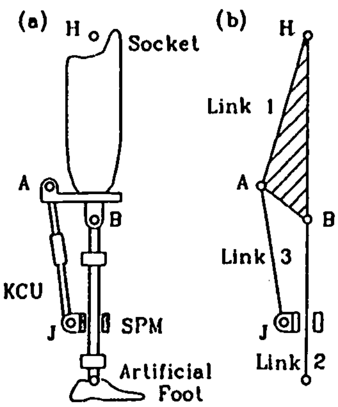

Figure 1: (a) Schematic of the optimized jogging prosthesis showing the KCU and SPM. (b) Simplified three link model of prosthesis.

The Lagrangian formulation was employed to derive the equations of motion of the three link system and used to design the KCU and SPM. Similar procedures have been implemented for simulating human locomotion (4).

RESULTS

Design of KCU

The KCU consisted of a spring unit positioned posterior to a single axis knee joint and attached between the base of the socket and a slider joint on the shank tube. The spring size and position were determined by an optimization program which minimized the forces acting on it, as well as its weight. The force in the unit was calculated for prescribed knee moment and angle patterns taken from non-amputee joggers (5). The resultant knee angular pattern for a coil spring with a stiffness of 45.5 kN/m is shown in figure 2(a). The resultant motion compared well with the desired motion of a non-amputee jogger. Note that with conventional prostheses knee flexion is prohibited during stance, as the knee must maintain a hyper extended locked configuration.

Design of SPM

The main design goal of the SPM was to have the prosthesis simulate the swinging motion of the lower leg of non-amputee joggers. By subjecting the three link system to a prescribed hip and thigh trajectory, the resultant motion was determined with a numerical differentiation technique. The design entailed determining the location and stiffness values of the buffer springs; this dictated the range and rate of swing for efficient jogging. Figure 2(b) reveals a close concurrence exists between the resultant and desired angular knee patterns.

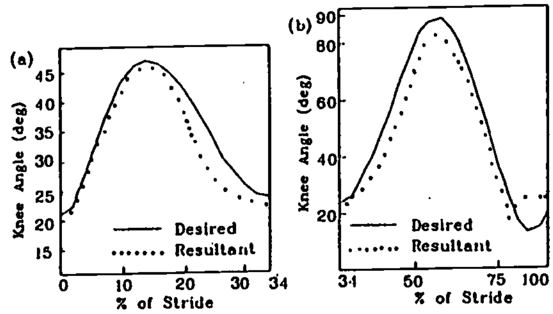

Figure 2: Computational results from the simulation study of the prosthesis for (a) stance and (b) swing. In both phases, the resultant knee angle patterns show close concurrence with the desired non-amputee patterns.

Design of Latch Mechanism
A spring-loaded latch mechanism was positioned inside the shank tube and used to couple links 2 and 3 during stance and decouple them during swing. The rotational energy in the swinging links was used to lock the latch mechanism prior to heel contact, while the ground reaction load transmitted during stance was used to unlock the latch.

Prototype Design
A photograph of the prototype prosthesis is pictured in figure 3. The weight-bearing, knee-flexing feature of the KCU is demonstrated in the figure.

DISCUSSION AND CONCLUDING REMARKS

The optimized prosthesis consisted of three major innovations. 1) It enabled the jogger to initiate heel contact with the knee in a flexed position, which helped to absorb the large impact forces. The knee continued to flex as the stance phase progressed, thus reducing pelvic rotation. Conventional prostheses have to be hyper extended at the end of swing so that they will be in a locked-knee configuration during the stance phase, thereby requiring the user to vault over the prosthesis into the toe-off position. This requirement also contributed to the increased reaction loads and excessive pelvic rotation. 2) As the knee flexed during stance, energy was absorbed in the main coil spring, and the KCU was so designed that the appropriate amount of resistance was provided throughout stance and stabilized the lower extremity. Most of the energy was returned to the jogger during the latter half of stance, which helped propel the jogger forward and upward. Note that

Figure 3: Prototpye of optimized jogging prosthesis.

with conventional walking prostheses, the knee remains locked in a hyper extended position, thereby providing minimal resistance against the large impact loads. 3) As soon as weight was removed from the prosthesis, a latch mechanism disconnected the KCU from the system and allowed the leg to rotate freely during the swing phase. A set of buffer springs established the limits of flexion and extension during swing and acted to reduce the total swing phase time. The upper buffer spring worked with the locking mechanism to provide 20° knee flexion to prior to heel contact. This closely simulated the normal jogging motion. These features of the prosthesis provided a more accurate simulation of the natural motion of the leg, and allowed for a symmetrical stepping pattern.

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GAIT SIMULATION AND THE DESIGN OF A PÆDIATRIC ABOVE-KNEE ENDOSKELETAL RUNNING PROSTHESIS

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Abstract

A unique approach combining quantitative measurements of human gait, analytical investigation and specification of mechanical components, and computer simulation techniques, was undertaken to design and evaluate a new prototype pædiatric above-knee endoskeletal running prosthesis. To overcome the performance restrictions of conventional children's prostheses, prosthetic components were designed to approximate kinematic and kinetic gait performance of able-bodied subjects by improving knee control and the body's centre-of-mass (COM) displacement profile. Experimental walking and running subjects were used to provide gait data for component design and the computer simulation of gait. Three components were proposed to improve running for children with an above-knee amputation (AKA): a four-bar linkage knee joint, a double-acting knee damper, and a telescoping shank spring-damper. For the first time, computer simulation was used for preliminary testing and evaluation of a complex above-knee prosthesis (AKP) over both the swing and support phases of gait. Kinematic simulation results indicated that the prototype prosthesis demonstrated both performance improvements and weaknesses compared with a conventional children's prosthesis.

Background

Children's Gait
An estimated 10,000 juveniles with an AKA across North America [1] are restricted to using simple functioning lower-limb prosthetic devices which place limitations on the type and intensity of physical activities they can undertake. On a daily basis the "average" child will perform activities of different types and intensities than the "average" adult. These activities might include running, jumping, and kicking a ball.

Child Amputee Gait
Able-bodied children differ from adults in terms of: i) stride length, ii) cadence, iii) swing time, iv) support time, and v) "comfortable" walking and running velocities [2, 3].

Limited study of child amputee gait has been performed. The group of Hoy, Zernicke, and Whiting [4, 5] performed studies of five children with AKA donning conventional prostheses. Compared to able-bodied counterparts, children with AKA walking showed differences in a large number of gait parameters.

Hoy, Whiting, and Zernicke [4] assert that knee stability at initial foot-ground contact of children with amputations is more critical than in adults due to relatively weak hip extensors. The children's prosthetic limb absorbs less shock at heel contact since ankle and knee joints cannot effectively dissipate the force. At toe-off, the user must compensate for this through increased hip/thigh muscular force over an increased hip flexion/extension range.

Running and Individuals with an AKA
Individuals with an AKA inexperienced at running tend to use a hop-skip method; this method (incorporating an extra hop) utilizes excessive hip and knee flexion to enable hip clearance over the supporting prosthesis [6]. Individuals with an AKA require knee extension during support, generate larger ground reaction forces and have severe problems in generating the propulsive impulse needed to maintain equal step lengths between natural and prosthetic limbs [7].

Above-Knee Prosthetic Advances
Present AKP prescriptions for children are limited to simple units with friction-based control of a single-axis knee; most designs have been scaled from adult units. These units are inadequate to address running. A number of promising knee controllers used in adult AKP have not been adapted to children's units: polycentric knee linkages, hydraulic and pneumatic controllers.

Computer Simulation of Normal and Prosthetic Gait
Most computer simulations of gait are based on applying experimentally-recorded or subjectively-specified forces to a simplified model of the human anatomy. The validity of these approaches is based on achieving satisfactory kinematic and kinetic results. Swing phase simulations [8] are typically planar, driven by experimental joint moments, while support phase simulations have applied heuristically chosen (or 'fudged') joint moments to planar [9] and three-dimensional [10] models to achieve gait resembling the experimental case.

Simulations of AKP gait have only been achieved for the swing phase [11, 12] by adding polycentric knees and various controllers to the typical able-bodied gait model.

Statement of Problem

- Conventional AKPs for children limit physical activity such as running. Prostheses should control: support phase knee stability, swing phase knee rotation, and impact energy storage and return.
- Typically, prosthetic design is a trial-and-error approach which is both costly and time consuming.

GAIT SIMULATION and PROSTHESIS DESIGN

Rationale

The objective of this research is twofold: 1) to develop a conceptual design for a running prosthesis for children with an AKA; and 2) to develop a computerized simulation of gait to enable preliminary testing and evaluation of prosthetic design ideas.

Design / Development

Since stability during support has been a major consideration, a polycentric knee was proposed to provide stability during heel-contact, while enabling the initiation of knee flexion at toe-off. In order to provide a stable mechanism over the widest range possible, knee linkage lengths were optimized through a computer program. *(see Figure 1)*

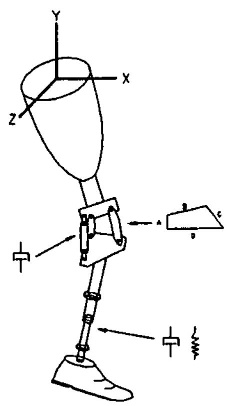

Fig. 1: Conceptual pædiatric running prosthesis.

Exaggerated knee flexion occurs during the swing phase of fast gait with conventional prostheses. A double-acting translational damper is proposed between the thigh and shank to provide swing phase knee flexion and extension control during walking and running gait, to enable faster shank return prior to heel contact. *(see Figure 1)*

Most individuals with an AKA tend to extend their prosthetic knees through heel contact, creating uncomfortable axial loading on their residual limb, with little return of the energy absorbed. A proposed spring-damper device placed in the shank would absorb the large forces at heel-contact during running, and provide energy return at toe-off, improving gait symmetry. *(see Figure 1)*

AKA Gait Simulation with Prototype Prosthesis

A three-dimensional model of the lower body was developed using DADS software [13]. The model, based on the model of Apkarian *et al.* [14], incorporated four of the six determinants of gait: knee flexion, hip flexion, knee-ankle interaction, and lateral pelvic displacement [15]. The model consisted of both swing side and support side elements: foot, ankle, shank, knee, thigh, hip, and a common head-arms-trunk segment. Each hip and ankle joint was modelled as three orthogonal axes; each knee joint was modelled as a planar joint. Inertial parameters of rigid body segments were calculated by modelling human segments as frusta [14]. Constraint of head-arms-trunk segment rotations were imposed to counteract exaggerated hip abduction/adduction and internal/external hip rotations. Joint rotation limits were based on clinical data [16]. *(see Figure 2)*

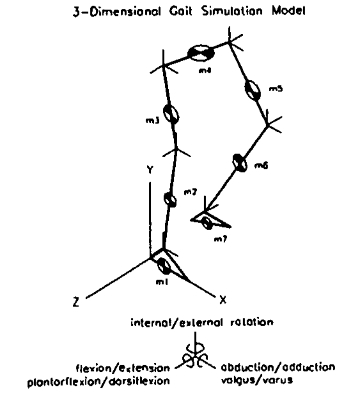

Fig. 2: Three-dimensional gait model (right).

Three-dimensional positional data were acquired (VICON, 50Hz, low-pass filtering at 6Hz) from an able-bodied female running subject (9 year old), providing: i) initial position, ii) initial velocity, and iii) joint moments about all axes. Moment data and initial positions were used to drive the model simulating normal running gait. The model was then modified to approximate the prototype prosthesis and AKP gait by adding components and removing ankle and knee joint moments drivers.

Evaluation

Simulation produced kinematic gait data to help in evaluating performance of the prototype prosthetic knee unit. *Figure 3* demonstrates simulation results of the support and swing phases of running gait with the prototype prosthesis.

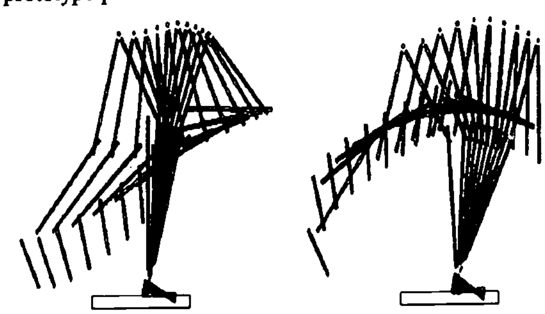

Fig. 3: Simulations of prototype AKP gait during support phase (left) and swing phase (right).

The prototype prosthesis exhibited stability under weight-bearing by limiting support-phase knee flexion *(see Figure 4)*. Improved control of swing phase knee velocity and range during running was demonstrated *(see Figure 5)* by the limited knee flexion range. The ability to achieve proper control of impact and support was demonstrated *(see Figure 6)* by the limitation of COM displacement.

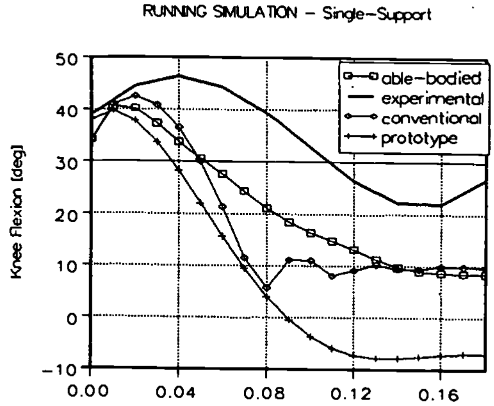

Fig. 4: Support phase knee flexion during running gait simulations.

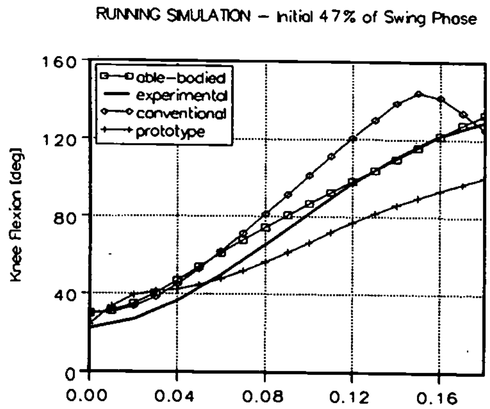

Fig. 5: Swing phase knee flexion during running gait simulations.

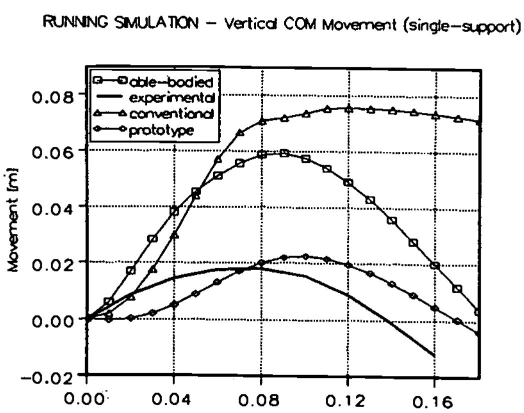

Fig. 6: Vertical COM movement during running gait simulations.

In comparing the running simulations between the prototype and the conventional prosthesis, the prototype demonstrated:

1. Slightly increased resistance to COM movement.
2. Significant improvement in vertical COM movement.
3. Decreased medio-lateral control.
4. Increased knee stability during the support phase.
5. Improved control of swing-phase knee flexion range.
6. Modifiable vertical ground reaction force and vertical COM properties.

Summary

A unique approach has been used to design and evaluate lower-limb prosthetic components. Quantitative gait analysis data have been combined with mechanical design methodology and computer simulation techniques to design and evaluate a new prototype pædiatric above-knee endoskeletal running prosthesis. Results of both evaluation method and prosthesis are promising.

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UPPER EXTREMITY NET JOINT FORCES AND MOMENTS DURING WHEELCHAIR PROPULSION

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The purpose of this study was to determine the net joint forces and moments at the wrist, elbow and shoulder during wheelchair propulsion and to show how these forces were related to joint position. Two experienced male wheelchair users pushed a Quickie1 wheelchair secured to the CSUS wheelchair dynamometer fitted with the 3-channel SMART^{wheel} on its right side. Video and force data were simultaneously collected for speeds from 1.34 to 1.79 m/s for 3 minutes for each subject. Subsequent calculations of joint moments were completed by combining kinematic variables, push rim forces and anthropometric data. The data showed that the forces at each joint varied for both subjects in terms of peak forces, where they occurred in the propulsion phase and how quickly they developed. Also, the peak net joint moments occurred at different joint angles for both subjects from trial to trial. Considerably more data must be gathered and analyzed before definitive statements can be made about joint stresses and before this information can be utilized by the clinician.

Introduction

A determination of net joint forces and moments acting at a joint during locomotion provides the clinician and researcher with information related to the level of stress borne by the joint structures. The upper extremity during wheelchair propulsion has not been studied in this manner due to the lack of adequate instrumentation for determining push rim forces at the hand. The SMART^{wheel} (1) allows push rim forces to be determined during wheelchair propulsion (2). Utilizing this information Cooper et. al. (3) presented a technique for determining net joint forces and moments utilizing an inverse dynamics approach. The purpose of this study was to determine the net joint forces and moments at the wrist, elbow and shoulder during wheelchair propulsion and to show how these forces were related to joint position.

Background

The kinematics of wheelchair propulsion have been studied by a number of researchers (4). Kinematic data by itself does not provide sufficient information for the clinician to implement appropriate rehabilitation intervention strategies or the engineer to incorporate this information into wheelchair design changes. A number of researchers have attempted to study joint forces during wheelchair propulsion but they have not been successful due to the lack of adequate instrumentation for determining push rim forces at the hand. The SMART^{wheel} (1) is the first device which does this. The importance of evaluating net joint forces and moments is that it allows the clinician and researcher to study the level of stress experienced by the joint structures during propulsion. These forces can then be studied for different speeds of propulsion, injury level, user experience, and wheelchair type and fit. This is the first study known to the authors which presents realistic and accurate joint forces during wheelchair propulsion. The primary objective of this work is to provide appropriate information for the clinician to use in the rehabilitation process--designing training protocols, modifying stroke mechanics, and for the engineer to make appropriate changes to the wheelchair which allow the user to optimize efficiency and reduce trauma to the upper extremity.

Methods

Two experienced male wheelchair users pushed a Quickie 1 wheelchair which was secured to the CSUS wheelchair dynamometer (5) and fitted with the SMART^{wheel} on its right side at 1.34 to 1.79 m/s for 3 minutes. Subjects monitored their speed by viewing a digital tachometer mounted at the front of the dynamometer. Data were collected at 75 Hz per channel for approximately 10 complete strokes near the end of the 3 minutes. Processing of the signals from the beam-mounted strain gauges resulted in a determination of the forces in the x and y direction and moment about the z-axis (x-anterior-posterior; y-superior-inferior, z-medial-lateral). An optical encoder provided information about angular motion of the wheel. Simultaneous video data were collected at 60 Hz from a right sagittal view of each subject. Video data were synchronized with the force data utilizing a reset of the optical encoder at top dead center. For analysis, the video data were interpolated to a time base of 75 Hz utilizing a spline function to match the force data. Subsequent calculations of joint moments were completed by combining kinematic variables, push rim forces and anthropometric data utilizing a method described by Cooper et al. (3). Joint angle data were determined from digitized values using a Peak 5 System (Peak Performance Technologies, Inc.). Data were analyzed for 3 complete strokes for both subjects with routines written using MATLAB (Mathworks, Inc.).

Results

The push rim force data from this study has been presented elsewhere (2). Representative curves of forces and moment are given Figure 1.

Peak Values. To evaluate the data, net forces and moments at the wrist, elbow and shoulder were analyzed in terms of maximum values (MaxFx (N), MaxFy (N), MaxMz (N-m)), percent of propulsion stroke where maximum occurred (%strkFx, %strkFy, %strkMz), rate of rise of forces (RORFx (N/s), RORFy (N/s)), and impulse values--linear for Fx (ImpFx (N*s)) and Fy (ImpFy (N*s)) and angular for Mz (ImpMz (N-m*s)). Table 1 presents the results from this analysis.

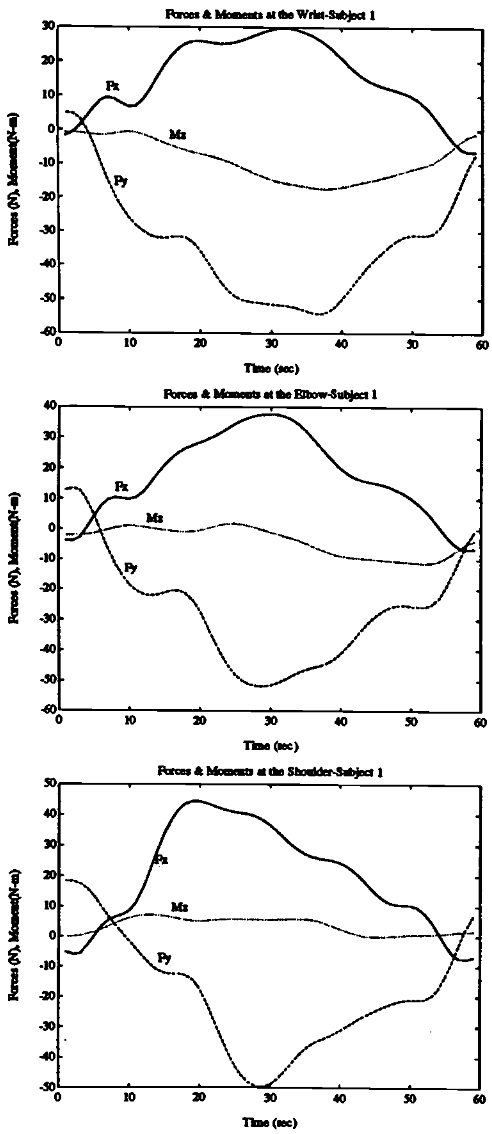

Figure 1. Forces and moment at the Wrist, Elbow and Shoulder for Stroke 1 of Subject 1.

The results of this part of the analysis showed that the maximum joint forces in the x-direction (maxFx) were similar for S1 and S2 and increased going from the distal to proximal joint. (wrist to shoulder) S1 developed considerably larger forces in the y-direction (maxFy) at all joints. S1's maxFy forces were larger than those in the x direction whereas S2 exhibited maximum Fy forces which were similar or smaller in value than the maximum Fx forces. The part of the propulsive phase where peak forces occurred were generally earlier for the Fx forces than the Fy forces for both subjects at all joints. Peak Fx forces occurred approximately 1/3 of the way into the propulsive phase whereas peak Fy occurred between 50-60% into this phase. The ROR of both forces varied considerably between subjects and from joint-to-joint. S2 developed greater moments than S1 at all joints. S2 produced the largest moments at the elbow whereas for S1 the wrist moment was the greatest.

Table 1. Net Joint Force and Moment Variables Averaged over 6 strokes for both subjects.

Wrist	MaxFx	%strkFx	RORFx	ImpFx
	31.9	36.4	123.9	13.3
	(3.7)	(11.1)	(38.6)	(1.6)
	MaxFy	%strkFy	RORFy	ImpFy
	-48.9	53.2	-126.5	22.9
	(21.6)	(15.0)	(54.5)	(8.5)
	MaxMz	%strkMz		ImpMz
	26.4	62.5		13.3
	(7.6)	(4.3)		(6.3)
Elbow	MaxFx	%strkFx	RORFx	ImpFx
	37.5	36.5	144.7	14.0
	(3.1)	(10.8)	(48.1)	(1.7)
	MaxFy	%strkFy	RORFy	ImpFy
	-47.9	56.3	-113.9	18.6
	(19.5)	(4.0)	(51.4)	(8.6)
	MaxMz	%strkMz		ImpMz
	25.4	67.1		11.9
	(14.8)	(11.3)		(9.0)
Shoulder	MaxFx	%strkFx	RORFx	ImpFx
	46.3	30.6	234.2	15.8
	(4.2)	(12.4)	(118.5)	(2.0)
	MaxFy	%strkFy	RORFy	ImpFy
	-44.3	55.8	-110.5	15.0
	(21.1)	(15.4)	(59.1)	(7.9)
	MaxMz	%strkMz		ImpMz
	20.1	44.0		9.3
	(15.1)	(26.6)		(8.0)

Joint Moment-Angle Relationships. The angles were all determined in the sagittal plane and represented flexion and extension at the 3 joints. The convention for joint angles was that 180 degrees at the elbow represented full extension while at the wrist this was with the hand in the neutral position (flexion less than 180 degrees and extension greater than 180 degrees). Joint angles at the shoulder were determined between the arm and the trunk, with zero at the point where the trunk and arm were aligned. Less than zero indicated that the arm was anterior to the trunk and greater than zero was the arm posterior to the trunk. Figure 2 shows typical moment-angle plots for all 3 joints.

Both subjects showed some variability from stroke to stroke in terms of how the moment was produced throughout the range of motion. There were considerable differences between the subjects. The maximum net shoulder moment for both subjects occurred between 20-40° of extension. Both Subjects showed a rapid rise in elbow extensor moment at the beginning of the stroke, with the elbow at about 120°. This moment value began to decrease at approximately 150° for S1 and 170° for S2. At the wrist, the peak moment occurred at close to 220° for S1 and close to 190° for S2.

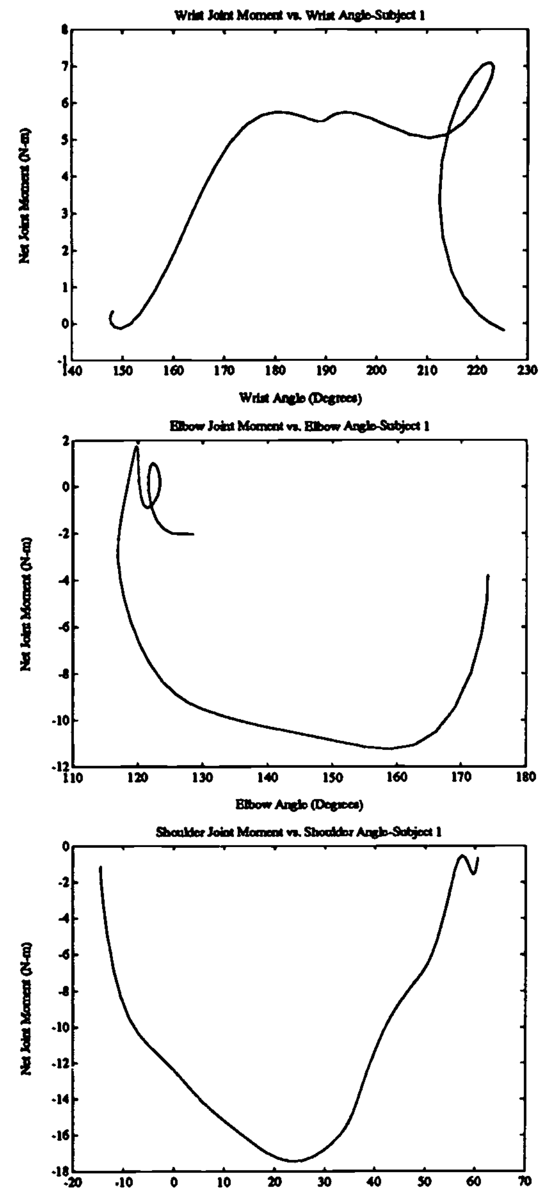

Figure 2. Joint Moment-Joint Angle Graphs of the Wrist, Elbow and Shoulder for Stroke 1 of Subject 1.

Discussion

The data showed that the forces at each joint varied for both subjects in terms of peak forces, where they occurred in the propulsion phase and how quickly the forces developed. Also, the peak net joint moments occurred at different joint angles for both subjects and the way in which the joint moments were produced throughout the full range of motion was different from trial-to-trial and between subjects. The larger moments at the elbow for S2 indicate that these joint structures were being stressed to a greater extent than at the other joints. At the wrist, peak moments occurred when the hand was close to its most stable position for S2 (i.e., close to 180°) and in a slightly extended position for S1. The results from this study show that net joint moments and forces are considerably variable within a subject and between subjects. It is therefore important to determine how different conditions of propulsion, such as speed, level of injury, user experience, fit in the chair, and type of chair, affect these joint forces.

Summary

Considerably more data must be gathered and analyzed before definitive statements can be made about joint stresses and before this information can be utilized by the clinician. More work needs to be done to accurately model the center of pressure on the hand as this will influence the net joint moment at the wrist. More subjects must be tested under varying conditions and the analysis needs to be extended to the other planes of motion. Similarly, changes in wheelchair design can only be implemented once we understand how various design features, conditions of propulsion and an individual's physical characteristics influence net joint forces and moments.

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DIFFERENTIAL PRESSURE WALKING ASSIST

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ABSTRACT

We have applied the concept of differential pressure to reduce the loads on the lower body during upright standing and walking. The first prototype of a differential pressure walking assist device has been constructed to test the feasibility of the concept and to investigate cardiovascular effects on able-bodied subjects during standing. The device consists of an inflatable conical reinforced vinyl skirt attached to a circular base holding a force plate. Buoyant forces between 0 and 100% of body weight were demonstrated without adverse cardiovascular effects in this study population.

STATEMENT OF THE PROBLEM

An improved walking assist device, which comfortably reduces the ground reaction force and lower limb muscle and joint forces, is needed for patients recovering from neurologic diseases and orthopedic procedures.

BACKGROUND

A variety of techniques have been used to help partially suspend a patient's weight during walking rehabilitation, including water immersion, parallel bars, walkers, overhead suspensions, and therapist-supported waist belts. Most of these techniques have disadvantages associated with them, in addition to interfering with normal gait:

- *water immersion* - inconvenience, possible infection of open wounds or incisions, viscous drag, and difficulty in modulating forces
- *parallel bars and walker* - strength required of the patient's upper body
- *hand-held waist belts* - physically stressful for the therapist supporting a patient's weight; possible patient falls
- *overhead suspension harness* - locally high interface contact pressures.

Lower body differential pressure chambers large enough to enclose a treadmill have been developed at the Life Science Division of NASA-Ames Research Center [1,2,3]. These chambers are being used in research to investigate the application of differential pressure to exercise in space, and to simulate hypo- and hyper-gravity locomotion [4].

RATIONALE

We have applied the concept of differential pressure to reduce the loads on the lower body during upright standing and walking. To create the pressure differential, the subject's lower body is enclosed in an inflatable chamber isolated from the upper body at the waist by a flexible, air-tight seal.

During quiet standing tests, the ground reaction force, the vertical force between the ground and the plantar surface of the foot for an upright subject, decreased proportionally with increasing pressure. The ground reaction force is the vector sum of the downward force due to gravitational acceleration and the upward differential pressure force. The force due to air pressure is equal to the product of the pressure difference and the waist cross-sectional area. The line of action of the resultant force passes through the area centroid of the waist cross-section, which is near the body center of mass. An additional upward shear force is created by the waist seal against the subject due to area of the flexible waist seal exposed to the pressure.

Since the upper and lower body air pressures are uniformly distributed over the body surfaces, the resultant force is not felt as a localized force lifting up on the body. The subject simply feels lighter, similar to being buoyed up by waist-deep water. The lifting force can easily be controlled by adjusting chamber pressure to adapt to an individual patient's needs as he or she progresses through rehabilitation.

DESIGN

The first prototype of a differential pressure walking assist device has been constructed to test the feasibility of the concept and to investigate cardiovascular effects on able-bodied subjects during standing. The device consists of an inflatable conical reinforced vinyl skirt attached to a circular plywood base holding a force plate (see Figure 1). The subject steps through the waist seal onto the force plate, pulls the skirt up, and positions the elastic neoprene flap seal at the waist before inflation.

A computer controls a servo-valve connected to a blower which regulates the pressure in the chamber, while simultaneously recording and displaying pressure and ground reaction force.

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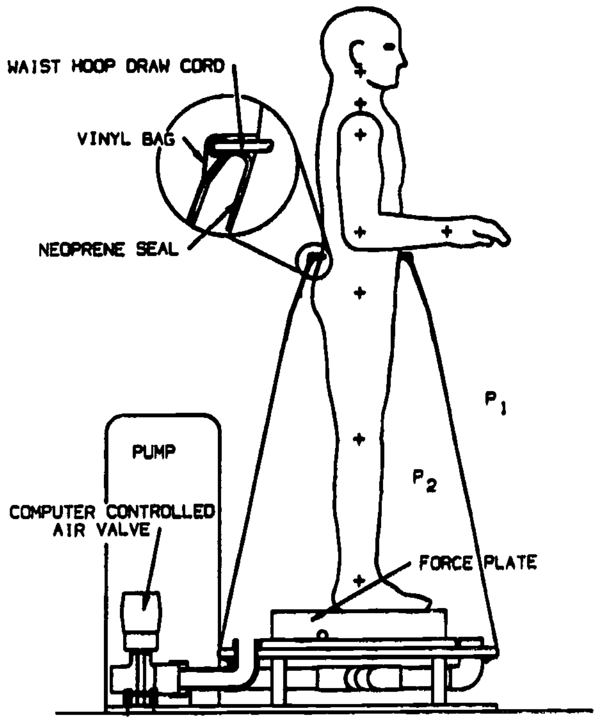

Figure 1. Illustration of inflatable lower body positive pressure chamber to test the feasibility of the differential pressure walking assist.

EVALUATION

A pilot study of eight healthy consenting male subjects between the ages of 29 to 52 established the relationship between ground reaction force and pressure, and evaluated the cardiovascular responses. Blood pressure and heart rate were measured every two minutes during two protocols and the results compared to a supine resting baseline. In the first protocol the pressure was changed stepwise from 0 to 45 mmHg and back to zero in 15 mmHg steps at two minute intervals. In the second protocol, each subject's response to rapid changes in pressure was evaluated by pressurization to 45 mmHg for 15 minutes and then rapid return to ambient pressure.

Changes in heart rate and blood pressure were within the range of values observed between baseline and standing.

At 45 mmHg, mean reduction in vertical ground reaction force was 75%, and ranged from 60% to 100%. Variation in per cent reduction of ground reaction force is likely due to variability in body habitus and waist seal placement on the body. We also found as expected that the pressures necessary to substantially unload subjects were significantly lower than pressures predicted by waist cross-sectional area alone, due to the upward shear force from the waist seal.

DEVELOPMENT

Prototype development is continuing to allow enclosure of a treadmill at the bottom of the inflatable conical skirt. With assistance from a therapist, a patient in a wheelchair will be able to roll up a ramp, enter the skirt through an air-tight zippered entrance, and stand up on the treadmill with the aid of external handrails. The skirt will be inflated to the desired pressure before starting the treadmill.

If results of ongoing work continue to be encouraging, a commercial version of the device will be developed in collaboration with an industrial partner.

DISCUSSION

The use of lower body positive pressure is a comfortable way to reduce the effects of gravitational forces. Since the upward resultant air pressure force acts at or near the center of mass of the body, we anticipate walking in the device will resemble normal gait but with proportionally reduced musculoskeletal forces. There is contact with the patient only at the waist seal. The arms are free to move as the pressure and shear force in the seal do all of the lifting, and the waist seal provides front, back and lateral support to prevent falling.

The first trials of this device have been limited to able-bodied healthy adult subjects. Levels of lower body positive pressure necessary to unload subjects' legs are relatively benign. For instance, the maximum pressure of 45 mmHg attained in this initial study is equivalent to the hydrostatic pressure of two feet of water.

Additional studies are planned to further determine the efficacy and safety of the device for use in rehabilitation before testing with patients.

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ACKNOWLEDGMENTS

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Fabrication of machined parts, the wooden base, and pressure system connections are the work of James Anderson, modelmaker machinist at the RRD Center. Jeff Emery and Josh Beach contributed to the development of the pressure control and data acquisition systems at NASA-ARC. The neoprene waist seal was constructed by Stan Stugen at Stan's Skin Diving Shop in San Jose, California.

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Measuring Leg Motion Changes Following Vertical Vestibular Stimulation: A Case Study

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ABSTRACT

This laboratory is investigating the effects of vertical vestibular stimulation on lower limb motion in individuals with cerebral palsy. A case study of an 18 year old subject with spastic diplegic cerebral palsy is presented. The subject's active and passive leg motion was measured before and after vestibular stimulation. Seventeen attributes were calculated from these measurements. Statistical analysis showed a significant difference ($p<.05$) in the measurements before and after stimulation in 16 out of the 17 attributes. The results indicate that this type of vestibular stimulation may have had an effect on this subject's active and passive leg motion. Further implications are noted.

INTRODUCTION

When designing a therapy program for individuals with neurological impairments, therapists will often include some type of vestibular stimulation in their treatment regime. Researchers claim that vestibular stimulation offers benefits such as normalization of muscle tone, improved postural alignment and improved balance reactions[2][3][6]. Stimulation is often achieved by placing the individual in a swing or on a platform and spinning them. In an alternative method, hippo therapy, the individual is stimulated by being moved primarily in the vertical direction. In a review of hippo therapy literature, Engel[1] reports effects such as decreased spasticity, improved trunk control and increased walking stability.

OBJECTIVE

The authors and their co-workers have built a platform that simulates the vertical movements of a trotting horse in order to study it's effect on individuals with cerebral palsy. The subject 'rides' on the vertically moving platform and is then measured to detect changes in active or passive leg motion. Use of this platform allows the direction, frequency and magnitude of stimulation to be controlled for more objective evaluation of any effects that it may produce.

METHOD

The subject to be presented in this case study is an 18 year old female with spastic diplegic cerebral palsy. She attends high school and is essentially independent in her activities of daily living. She walks with some gait deviations and has spasticity in her quadriceps.

The vertical motion platform used in this case study is shown in Figure 1. The subject was placed on the platform in a secured chair. The platform was then oscillated vertically with an amplitude of 3.5 inches and a frequency of 1.57 Hertz.

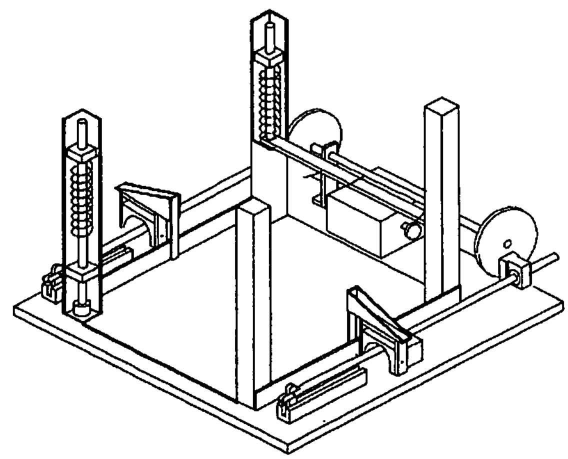

Figure 1. Vertical Motion Platform

The leg position information was collected using a magnetic sensing device, the 3SPACE® Isotrak® by Polhemus Navigational Sciences Division, McDonnell Douglas Electronics Company. The device uses the principle of low-frequency magnetic field technology to determine position and orientation of a sensor relative to a source. The subject was seated with the upper leg held fixed. The sensor was then placed at the lateral malleolus in order to record knee angle.

The subject was asked to perform three leg motion tests before and after fifteen minutes of stimulation. First, the leg drop pendulum test was performed to test passive motion [4]. The leg was held so that the knee was extended as far as the subject could comfortably tolerate. When the subject's quadriceps muscle appeared to be relaxed, the leg was then dropped. Position information was recorded until the leg stopped moving. Next, the 'kick' test was performed. The subject was asked to kick a hanging ball as hard as she could. Lastly, the 'swing' test measured the motion as the subject was asked to swing her leg back and forth for ten seconds. Each test was repeated six times before and six times after stimulation.

DATA ANALYSIS

The data analysis included looking at seventeen measures of performance based on information from the three tests. The attributes measured are as follows:

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1. For the pendulum test:

undamped natural frequency(sec^{-1}): $\omega_d = \frac{\pi}{t_p}$

(t_p = time of peak position)

damping ratio: $\zeta = \sqrt{\frac{1}{x^2+1}}$

($x = \tan\left(\omega_d t_r\right)$ and t_r = the rise time)

settling time(sec): t_s = the time for the leg to settle within 1% of θ_f; (θ_f = final resting angle)

maximum angle(degrees): $\theta_m = \theta_i - \theta_f$

(θ_i initial angle, θ_f = final resting angle)

maximum drop(degrees): $\varphi_m = \theta_i - \theta_p$

(θ_p = angle at first peak)

average velocity(radians/second): υ_a = slope of the first order fit of $\langle\theta_i(t) - \theta_p(t)\rangle$

maximum velocity(radians/second): υ_m = point where $\frac{d^2}{dt}\langle\theta_i(t) - \theta_p(t)\rangle = 0$

maximum spectral density: ρ was calculated by applying a fast fourier transform on the oscillatory part of the signal. This was done by removing the DC component, multiplying by a hamming window, filling to 4096 points with zeros, and dividing each value by the number of points in that particular trial. From this the maximum energy is found.

2. Kick test attributes:

Kick is defined as a ballistic movement; continuous and in one direction.

maximum range of motion(degrees): $MROM = \theta_i - \theta_p$

(θ_i = initial angle and θ_p = peak angle)

maximum deflection(degrees): $d_m = \theta_o - \theta_e$

(θ_o = the angle where the velocity = 15 rad/sec and θ_e = the final position of the kicking stroke)

average velocity(radians/second): υ_a = slope of the first order fit of $\langle\theta_i(t) - \theta_p(t)\rangle = 0$

maximum velocity(radians/second): υ_m = point where $\frac{d^2}{dt}\langle\theta_i(t) - \theta_p(t)\rangle = 0$

3. Swing Test Attributes:

maximum range of motion(degrees): $MROM$ = difference between the max. and min. angle

maximum spectral density: ρ (same description as for the pendulum test)

total power: P = the integral of the spectral density curve

frequency at maximum power: f

moment of inertia: M = Area moment of inertia of the power spectral density curve about the frequency of maximum power. This moment represents a measure of the dispersion of frequencies.

RESULTS

Visual inspection of the data (see Figures 2, 3 and 4) indicates a change in passive and active leg motion following stimulation. Mean values and standard deviations for particular attributes are presented in tables 1, 2 and 3. Statistical methods were based on those outlined in Ottenbacher's chapter "Statistical Analysis of Single System Data"[5]. Autocorrelation calculations were performed on the data in order to

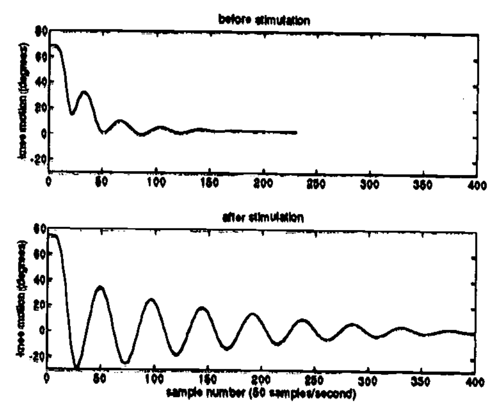

Figure 2. Pendulum Test

rule out serial dependency (due to practicing or learning effects). Since no serial dependency was detected, an analysis of variance (f-test) was used to test for statistical significance. A significant difference was seen in thirteen of the attributes at the 99%confidence level. Three attributes were significant to the 95% confidence level and one was significant to the 90% confidence level. Tables 1, 2 and 3 give information regarding the mean (μ), the standard deviation (σ) and the p-values for each of the attributes.

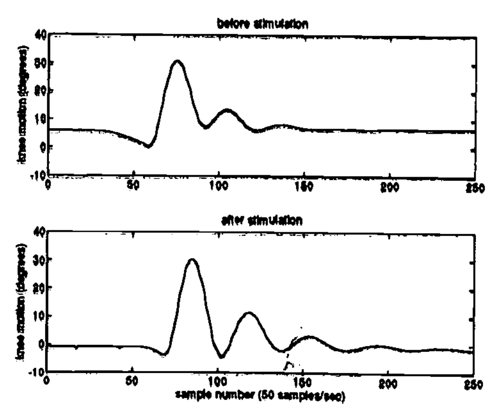

Figure 3. Kick Test

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Leg motion changes following vestibular stim.

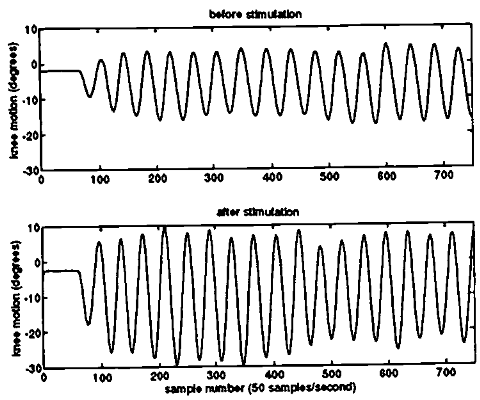

Figure 4. Swing Test

Table 1: Pendulum test

Attribute	μbefore	σbefore	μ after	σ after	p
Max angle(θ_m)	64.30	2.61	70.75	2.57	.01
Max Drop (θ_d)	51.11	5.16	92.73	9.30	.01
Ave Vel (v_a)	3.65	0.26	4.94	0.32	.01
Max Vel (v_m)	8.33	1.04	10.34	0.41	.01
Damping (ξ)	2.0	0.00	0.72	0.11	.01
Nat Freq (ω_d)	11.05	1.08	8.27	0.8-	.01
Sett time (t_s)	3.18	0.31	7.36	0.67	.01
Max Dens (ρ)	0.29	0.46	1.08	0.01	.01

Table 2: Kick test

Attribute	μbefore	σbefore	μ after	σ after	p
Max ROM	28.52	1.01	31.10	1.35	<.01
Max Defl (d_m)	32.55	3.38	29.04	1.57	<.05
Ave Vel (v_a)	2.09	0.04	2.31	0.12	<.01
Max Vel (v_m)	3.99	0.33	4.27	0.24	<.10

Table 3: Swing test

Attribute	μbefore	σbefore	μ after	σ after	p
Max ROM	22.00	2.45	41.07	4.92	<.01
Max Spec (ρ)	0.79	0.23	2.80	0.60	<.01
Total Pow (P)	0.12	0.03	0.42	0.11	<.01
Freq MP (f)	1.23	0.06	1.30	0.03	<.05
Mom Inert (M)	0.26	0.01	0.29	0.02	<.05

It is interesting to note that, before stimulation, the subject was asked to swing her right leg. She replied "I can't unless I swing both legs together". She appeared unable to dissociate the movement of one leg from the other. After stimulation, when asked again, she immediately began swinging her right leg only.

DISCUSSION

Results indicate that there appears to be a difference in this subject's leg motion before as compared to after stimulation. Some of the effects seen following stimulation, such as decreased damping of motion, increased active and passive range of motion and increased velocity of motion indicate a possible decrease in muscle stiffness. This may be related to a decrease in muscle spasticity. In addition, the "catch" that is seen before stimulation in the pendulum test (see Figure 2.) as the leg begins to fall disappears after stimulation. This could indicate a decrease in spasticity as well. Further research with larger sample populations is crucial in order to make decisions about the efficacy of treatment regimes that include vestibular stimulation.

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FUNCTIONAL ASSESSMENT OF A TRICEPS ORTHOSIS FOR C5/C6 TETRAPLEGIA

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ABSTRACT

Persons with spinal cord injury at the C5/C6 cervical level typically have relatively well preserved biceps function, but minimal or no voluntary control of triceps. Our previous work has showed that this results in deficiencies in speed and accuracy of elbow movements, as well as a reduction in the reachable workspace, and that these deficiencies can be corrected by the addition of constant extensor torque and damping at the elbow. In this report we describe a prototype mechanical orthosis, worn at the elbow, and illustrate improvements in function obtained by users with C5/C6 tetraplegia.

BACKGROUND

Spinal cord injury (SCI) results in the loss of voluntary control of muscles and causes decreased mobility to an extent depending on the level and completeness of injury. Persons with injuries at the C5/C6 cervical level, whose biceps function is relatively well preserved, have little or no voluntary control of triceps. Without use of the triceps, which is the primary elbow extensor, they lose the ability to, for example, reach overhead. In addition, they face limits on the range, speed, and accuracy of arm movements; this loss of *control* of the arm occurs even in a task in which the biceps does the work.

Because even a small amount of biceps spasticity can result in a chronic torque imbalance at the elbow joint with a resultant flexed, supinated forearm posture, a number of orthotic devices have been developed to reverse elbow flexion postures or contractures (see (1) for references). On the other hand, the control deficit during biceps tasks has received little attention. Our recent studies of fast elbow flexion movements in C5/C6 tetraplegics have revealed deficiencies in movement speed and accuracy compared with control subjects (2). Patients' movement times were, on average, twice those of control subjects, and their errors were twice as large when they attempted 10° movements. When we used a torque motor to provide a 2.5 Nm constant extensor torque as an "artificial triceps," however, patients' movement speeds increased and their accuracy was indistinguishable from that of control subjects (2). We also used the torque motor to electronically emulate the addition of up to 1.0 Nms/rad of damping and the substitution of a linear extensor spring for the constant extensor torque. We found that the addition of damping appears to contribute to accuracy and the subjective feeling of being in control; the linear spring increased oscillations and gave subjects a feeling of instability (3). The realization of this concept in an orthotic device requires a constant-torque spring to provide the extensor torque and the optional addition of a damping element.

ORTHOSIS DESIGN

The prototype orthosis is illustrated in Fig. 1. The four cuffs were fabricated of carbon fiber lamination braid and lined with T-foam™. As we were unable to locate a commercially available rotational constant torque spring, we used a prestressed power spring which could be prewound to an appropriate torque (1.25 Nm each side) and maintained that torque within 10% over the limited (160°) range of usage. Damping was provided by adjustable linear air dampers (Airpot Corp.)

ORTHOSIS EVALUATION

Subjects were outpatients of the Spinal Cord Injury Service, selected on the basis of relatively normal biceps strength and little or no voluntary strength in triceps.

Control test. To demonstrate improvement in control aspects of arm motion, one subject performed single-joint movements to a visual target, with and without the triceps orthosis (10 trials under each condition). He sat in his own wheelchair with the arm supported on a table at shoulder height and strapped to a manipulandum, allowing horizontal rotation of the arm at the elbow. An oscilloscope displayed two traces: one with the initial and then final target level, and the other showing the subject's current arm position. The subject aligned with the initial target line then moved "as quickly and accurately as possible" to

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the final position when the target shifted. Movements of 10° and 30° were performed.

Average (±SD) movement times decreased from 312±34 msec to 241±31 msec in 10° movements and 468±49 msec to 294±35 msec in 30° movements. Acceleration and deceleration times were both improved. Movement accuracy was similar with and without the orthosis, although subjects moved much faster with the brace. These faster movements, made without the brace, would have resulted in large overshoots of the targets. These improvements in kinematic performance are similar to those of our previous studies (2,3).

Reaching test. Three subjects performed reaches to a 60 cm high, 120 cm wide "target board", placed on a table 30 cm in front of their chest. Targets were 4 cm diameter holes arranged in 4 rows of 7 columns, spaced 18 cm apart. A lightweight pen was strapped to the subject's index finger. He was instructed to bring his hand from an initial resting position on the table to each target in turn. Success was based on ability to place the pen into each hole and maintain that position.

Results differed in each subject because this test of three-dimensional reaching requires coordinated movement and strength of several muscle groups, including shoulder muscles. Subject 1, with no triceps strength and fairly weak deltoid muscles, showed marked improvement in his ability to reach the higher targets while wearing the orthosis (Fig. 2). Subject 2 had a trace of triceps but was limited by a biceps contracture in the tested arm; nevertheless he showed the ability to reach additional targets while wearing the orthosis. Subject 3 had a weak triceps and strong deltoids, and could reach all targets even without wearing the orthosis. This subject might not be a suitable candidate for the orthosis because he would show less functional improvement from its use. Overall, however, the orthosis brought more targets within reach, allowed faster reaches, and abolished arm collapse during overhead reaches.

Side reaching test: Subjects were asked to extend the arm to the side, then abduct it as high as possible while seated in the wheelchair. Subject 1 increased his vertical side reach from 129 to 142 cm; subject 2 from 112 to 127 cm; and subject 3 again showed no improvement.

Propelling the wheelchair: Without the orthosis, subject 1 could extend his arm only to a gravity-assisted 48° before gripping the rim. With the orthosis, he could further extend to 23°, allowing a longer power stroke.

Movement mimicking feeding: Subject 1's task was to repetitively pick up a light object from the table (using tenodesis grip) and bring it to his mouth, then return it to the table. Wearing the orthosis did not result in an increase in speed over 20 repetitions, but did result in fewer collisions with the chin, lips, and nose.

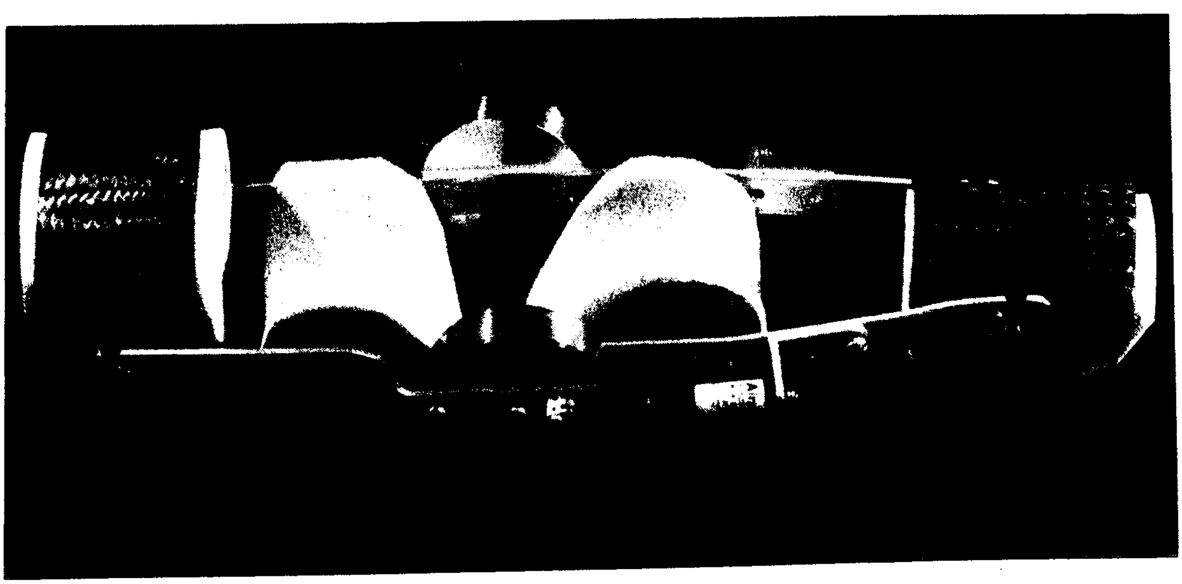

FIG. 1. A prototype version of the triceps orthosis. Note the springs (in cylindrical cases) and the dampers.

DISCUSSION

Basic research in neuromuscular motor control has recently led to recognition of deficits in control of arm movements of C5 tetraplegic subjects even in the absence of biceps spasticity or flexion contractures. This suggests that the applicability of elbow extension orthoses to the C5 tetraplegic population may be far wider than previously appreciated.

In rehabilitation practice, particularly involving prosthetic or orthotic devices, the simplest solution is often the best. The overall goal of this research project is to develop a lightweight triceps orthosis, composed of passive mechanical elements, to improve control of the arm, allow faster movements with improved accuracy, and provide increased reaching capacity for persons with C5/C6 tetraplegia. Alternative therapies to restore triceps function include tendon transfer surgery (4) and functional electrical stimulation (5).

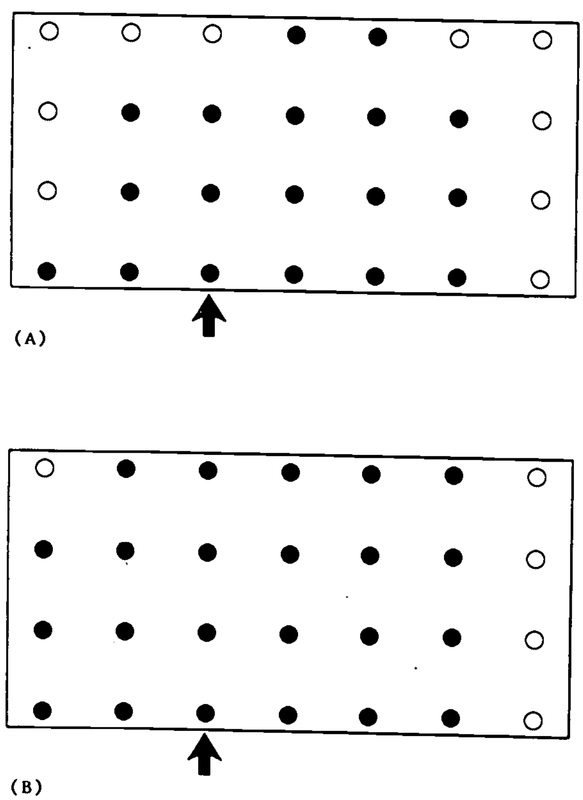

FIG. 2. Subject 1 could reach more targets (filled circles) with his right arm while wearing the orthosis (B) than without it (A). The arrow marks the midline of his body. The right-most row of targets was beyond his reach.

Although the prototype orthosis meets these goals for improved function, substantial further development is required to minimize its bulk and maximize its comfort and convenience. Even more than splints developed for temporary clinical purposes, an orthotic device intended for chronic use at home must excel in terms of convenience, long-term comfort, and attractiveness in order to be accepted and used. Current development efforts are directed toward eliminating the medial spring (which can get in the way during wheelchair propulsion), providing a pronation function, reducing the size and weight of the side bars, setting up a way to disable the spring mechanism during periods when the arm is inactive, and improving the donning/doffing procedure.

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THE ANALYTICAL INADEQUACIES OF TREADMILL- MOUNTED FORCE PLATFORMS

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This paper presents a critical review of a method for determining the maximal vertical force while walking on a force plate mounted on a treadmill by R. Kram and A.J. Powell[1]. The purpose of this device is to present the clinician with a viable means of measuring the maximum ground reaction force of an ambulatory subject over a number of consecutive limb contacts. With this design, however, the anterio-posterior (A-P) and medio-lateral (M-L) forces cannot be measured, leaving only the superio-inferior (S-I), or vertical, reaction force as the sole parameter to be studied. We believe that the estimation techniques implemented by the authors does not justify the neglect of the horizontal forces. We propose an alternate estimation technique but suggest that a hardware solution can resolve the three orthogonal forces.

Design

Kram and Powell's design consisted of a motorized treadmill fabricated from standard parts. A rectangular section was cut out of the middle of the treadmill to accommodate the mounting of the force platform. The force platform was positioned within the treadmill so that the top of the platform was flush with the supporting surface of the treadmill. This was done so that the belt would ride smoothly across both the treadmill and force platform and not exert any significant S-I forces onto the platform.

The force platform mounted into the treadmill structure was a commercially available AMTI (Advanced Mechanical Technologies, Inc.), model OR6-5-1. This platform is 1.21m long and 0.46m wide which is longer than the standard force platform. This size of plate was used to accommodate the sliding of the stance foot across the treadmill as the belt moves. According to Rosenrot et al.[2] the contact distance (D_c) for a walking adult male is calculated from the following relationship:

$$D_c = 0.665 + 0.25V$$

where V is the velocity of the belt. This allows this system to record the ground reaction forces of walking speeds up to ~2m/s. For a running adult male Munro et al.[3] empirically determined D_c to observe the following relationship:

$$D_c = 0.530 + 0.095V.$$

From this relationship the design is useful for running speeds up to ~7m/s.

The type of motor used (electric, gas, pneumatic, hydraulic, etc.) was not indicated. To reduce the effects of vibration noise, the motor was mounted next to the treadmill and aligned to drive the front drum through a rubber coupling.

Discussion

The design of this system does not allow for the measurement of the A-P and M-L forces. Assuming the belt is relatively stiff and the coefficient of friction between the belt and platform is low, any true horizontal forces applied to the belt above the force platform will not be seen by the platform but rather at the drums at either end of the treadmill. It is the drums that the belt is attached to, not the force platform. Any horizontal forces that are seen at the force platform are the result of vertical forces generating friction between the belt and the platform. The A-P reaction force that the force platform measures changes due to the moving belt and the variable friction that is being applied to the force platform as the S-I force changes.

The authors understand that horizontal forces cannot be measured with their design so they put their efforts into the justification that these forces are unnecessary. To justify the neglect of the horizontal forces, the vector product of the S-I and A-P forces was calculated. Rather than using actual signals to calculate the angle difference between the vector product and S-I component, estimations of the S-I and A-P forces were used. Kram and Powell estimated the S-I signal as 1/2 of a sine wave as shown in Figure 1. Also in Figure 1 is S-I force data for a walking subject that was measured using a standard floor mounted force platform.

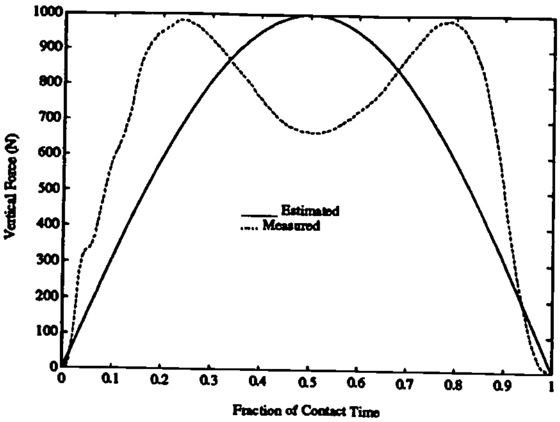

Figure 1. Single term sinusoidal estimation vs. measured vertical ground reaction force.

As can be seen by the plot in Figure 1, the sinusoidal estimation of the S-I force is not adequate. There is a significant amount of deviation from the measured signal.

Kram and Powell's estimation of the A-P signal is a full inverted sine wave at 1/10th the amplitude of the S-I signal estimation. This estimation is shown in Figure 2. Also shown in this figure is a typical A-P force signal that was measured from a walking subject using a standard floor mounted force platform. As can be seen from the plot, the sinusoidal estimation for the A-P force signal is also unacceptable. Although this estimation is better than that of the S-I component, neither can be construed as viable estimations.

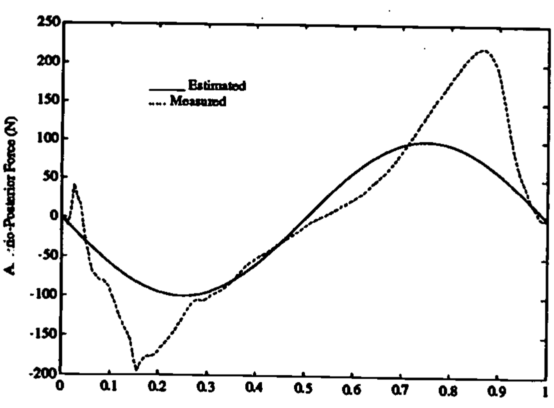

Figure 2. Single term sinusoidal estimation vs. measured A-P ground reaction force.

Figure 3 shows the vector product for the signal estimations that Kram and Powell used for their calculations. Figure 4 shows the vector products of the data that were measured using a standard floor mounted force platform.

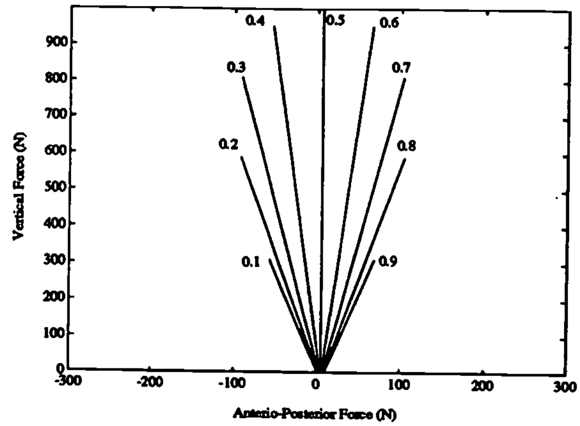

Figure 3. Vector product for the single term sinusoidal estimations every 1/10th of the contact time.

Figures 3 and 4 are scaled the same, making it fairly easy to observe that there are significant differences in the vector products from the estimated signals to the measured signals.

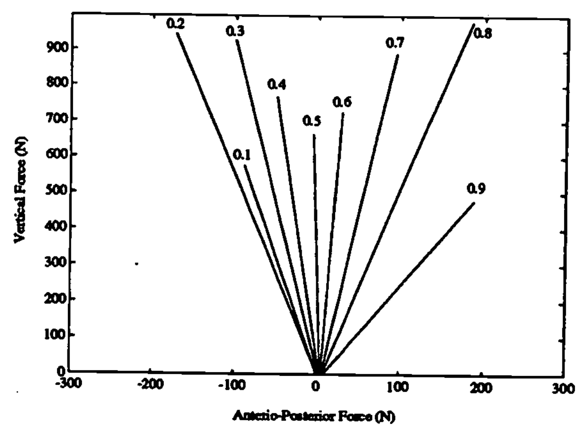

Figure 4. Vector product for the measured ground reaction forces every 1/10th of the contact time.

The magnitude of the vector product is a maximum of ~1.5% larger than the S-I magnitude. Kram and Powell calculate the vector product, using the estimations of the signals, to be a maximum of 11.3° from vertical. The vector product of the measured data was found to be a maximum of 30.6° from vertical. This is a profound difference (170.8%) and, therefore, invalidates their basic assumption that the horizontal forces can be neglected.

If it is necessary to make estimations of these signals, it would be much more accurate to use a two term Fourier Series estimation. Figure 5 illustrates the increased accuracy of a two term sinusoidal estimation of the vertical reaction force.

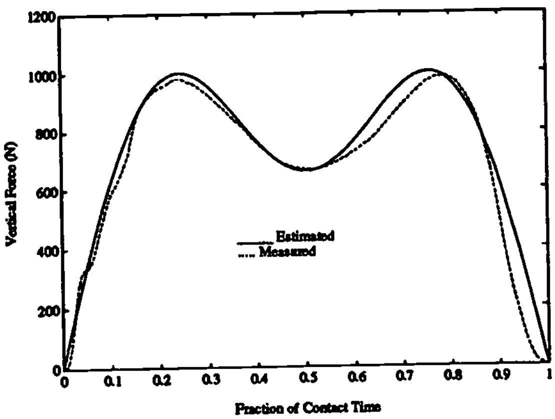

Figure 5. Two term sinusoidal estimation vs. measured vertical ground reaction force.

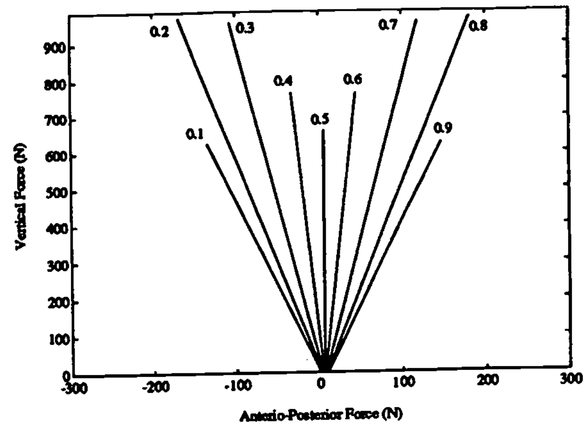

Figure 7. Vector product for the two term sinusoidal estimations every 1/10th of the contact time.

The equation used for this estimation, E_y is as follows:

$$E_y = | a \sin(\pi t) + a/2.75 \sin(3\pi t) |$$

where:

$$a = Fy_{max}/0.95 \quad \text{and} \quad t = 0 \rightarrow 1.$$

A two term sinusoidal estimation for the anterio-posterior forces is shown in Figure 6. The equation for this estimation is as follows:

$$E_x = -a/7 \sin(2\pi t) - a/20 \sin(4\pi t).$$

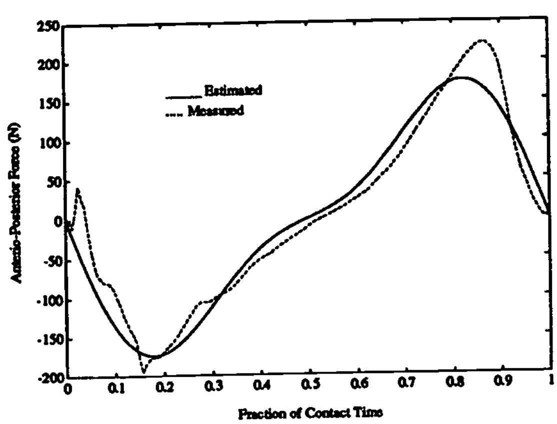

Figure 6. Two term sinusoidal estimation vs. measured A-P ground reaction force.

The vector product of the vertical and anterio-posterior forces, shown in Figure 7, more highly corresponds to that of the measured forces. The correlation coefficients[4] of the measured forces to the single and two term estimations for both the vertical and anterior-posterior forces are as follows :

Estimations	Vertical Force	A-P Force
Single Term	0.662	0.908
Two Term	0.983	0.973

Conclusion

Most biomechanists would agree that the usefulness of ground reaction forces are the subsequent calculations of net joint forces and muscle moments. This can only be done if the horizontal forces are accurately measured (at least the A-P forces for two dimensional analysis).

One approach to this problem is the instrumentation of the legs of a treadmill. If the force transducers are located on the legs, any force that is applied to the treadmill will be sensed and measured. These transducers must be triaxial (biaxial for 2-D analysis) to accommodate the measurement of all three force and three moment components. The treadmill must also be custom designed to maintain a high system natural frequency (>150 Hz). If the system natural frequency is too low, the measured force signal will be distorted. The speed of the belt must also be measured continuously so that the center of pressure can be adjusted appropriately.

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ACCURACY OF UPPER-EXTREMITY MOTION BY HEALTHY AND DISABLED SUBJECTS

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ABSTRACT

The effects of frequency and type of motion on attainable levels of accuracy in computer interface use are studied. Frequency limitations on accuracy in one-dimensional motion are presented for three subject groups. The maximum limiting frequency for accuracy of upper-extremity motion is found to be 2 Hz. The relative performance of three commercially available pointing devices is presented for two subject groups. A pen-type interface is found to offer the best results for healthy subjects, but the worst results for persons with movement disorders.

BACKGROUND

The upper-extremity dexterity of human users, i.e., coordination and speed of motion, is an important consideration in the design of teleoperative systems for rehabilitation (1). Determination of the intended command input when noise is present is a matter of concern to rehabilitation engineers (2). It is clearly desirable for a subject to operate a computer under conditions which allow him to use the type of bodily motion, and the frequency of motion, which offer the greatest accuracy. Previous studies have suggested that no single approach is best for all users (3), but it may be that certain general principles can be found.

The function of assistive computer interfaces is effective transduction of the user's wishes; that is, the person knows what he wants, but needs to communicate this to the computer. We have developed motion tasks which are simple and easy for users to anticipate, in order to study the effectiveness of interfaces to transmit subjects' commands to the computer. We define the Accuracy Index, a measure of the degree to which the subject stays with the target throughout the test. With the Accuracy Index we study the limitations which movement frequency places on continuous motion by healthy and disabled persons.

The assumption that the type of motion required by an interface is one that offers the user a good level of control accuracy is implicit in a person's use of an interface. In order to determine how attainable accuracy levels vary with different types of motion, we study three different pointing devices (mouse, pen, and trac-ball) and compare the relative error levels generated during the use of each.

RESEARCH QUESTIONS

1. What limitation does frequency of motion place on accuracy of motion by humans, particularly for rehabilitative computer interfaces?
2. Do different commercially available interfaces present significant differences in the levels of accuracy attainable by (a) healthy persons, and (b) persons with tremor?

METHOD

Two experiments are presented.

Frequency experiment: A small point-like target oscillated sinusoidally along a vertical line segment on a computer screen. The subject moved a standard Microsoft Mouse, attempting to keep the cursor pointing at the moving target. For each test, the mean-squared error (*MSE*) was calculated:

$$MSE = \frac{1}{N}\sum_{k=1}^{N} (t_k - o_k)^2, \qquad (1)$$

where t and o are the target and human output motions, respectively, k is a time index, and N is the total number of data samples in each test. The root-mean-squared error,

$$RMSE = \sqrt{MSE}\ , \qquad (2)$$

was then calculated. The RMS target amplitude was also calculated:

$$t_{RMS} = \sqrt{\frac{1}{N}\sum_{k=1}^{N} t_k^2}\ . \qquad (3)$$

The level of accuracy with which each subject generates the desired motion is represented by a measure called the Accuracy Index (*AI*), which we define as

$$AI = 1 - \frac{RMSE}{t_{RMS}}. \qquad (4)$$

An *AI* of zero indicates that the RMS error is the same as if the cursor had been left untouched in the center of the screen. Perfect motion generation results in an *AI* of unity.

Three groups of subjects completed the experiment: the *young* group (eight healthy subjects, age 23 ± 3); the *old* group (four healthy subjects, age 72 ± 1); and the *tremor* group (four tremor patients, age 65 ± 16).

Device Comparison: A target moved along the vertical line according to a broadband signal. The subject again attempted to keep the screen cursor pointing at the target. This experiment was done with a Microsoft Mouse, a Logitech Trackman trac-ball, and an Appoint MousePen (a pen-shaped mouse). The *MSE* (see equation (1)) was calculated and used to compare the devices.

This experiment was completed by five healthy subjects (age 27 ± 13) and two subjects with tremor (age 58 ± 21).

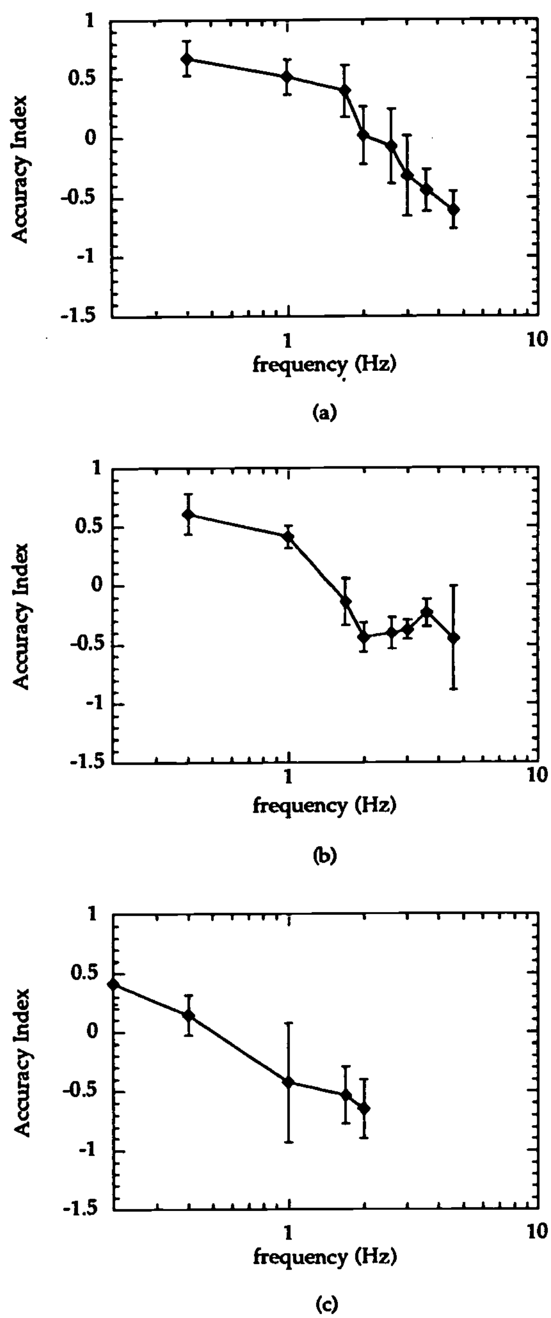

Figure 1. *AI* for frequency experiment. (a) Young group (8 subjects). (b) Old group (4 subjects). (c) Tremor group (4 subjects). Plots indicate mean ± standard deviation.

RESULTS

Frequency experiment: Figure 1 shows the *AI* results for the 1-D experiment. The results for the young group show a marked drop in accuracy beginning between 1.7 and 2.0 Hz, crossing zero at 2.0 Hz. The results for the old group cross zero at 1.6 Hz, and those for the tremor group cross zero much sooner, at 0.5 Hz. Therefore, above 2 Hz, the accuracy of all groups is worse than if they had not moved the cursor at all.

Device comparison: Figure 2 shows the results of the device comparison task. Each subject's results are normalized by the subject's mouse *MSE*, so the mouse results always appear as unity. Four of the five healthy subjects achieved their best results (i.e., lowest *MSE*) with the pen, and all five did better with the pen than with the mouse. The two tremor subjects both did considerably worse with the pen than with the mouse. The one tremor subject who completed the task with the trac-ball did much worse with the pen than with the trac-ball.

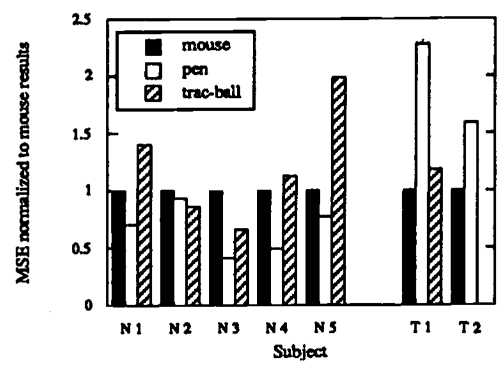

Figure 2. *MSE* results of the device comparison test. Results for each subject are normalized to that subject's mouse *MSE*. N1-N5 are the healthy subjects, and T1 and T2 are the tremor subjects. (The tremor subject T2 did not complete the trac-ball task.)

DISCUSSION

Frequency experiment: The data confirm the expectation that the young group would yield the best accuracy results. The young group is also the most consistent in accuracy. For the old group, the *AI* curves are similar in shape to those for the young group, but their results are slightly lower. Results for the old group are generally less consistent than for the young group. As expected, the tremor group yielded the worst *AI* results.

The *AI* results for the young group suggest that the accuracy limit, or bandwidth, for upper-extremity motion generation is 2 Hz, in that *AI* was less than zero above this point. For the old group and the tremor group, the *AI* zero-crossing frequencies are always less than 2 Hz. It then seems that 2 Hz is a maximum value for the accuracy limit, which may decrease due to factors such as age and movement disorders. We would expect this value to be no less than 1 Hz, since Mann *et al.* (4) reported that the average predominant frequency for everyday tasks is 1 Hz. We also would not expect this value to be considerably greater than 2 Hz, since Elkind and Sprague (5),studying pursuit tracking using rectangular target spectra, reported that signal-to-noise ratios decreased sharply when target bandwidths were above 1 Hz, and information rates at 2 Hz were half those at 1 Hz.

Device comparison: Larger-scale study is needed to derive conclusive results from the device comparison, but it appears that the pen is the best interface tested for accurate motion by healthy subjects. The results for the tremor subjects suggest that movement disorders such as tremor not only decrease subjects' overall accuracy of movement, but also alter the accuracy of different types of movement relative to one another. The difficulty of pen manipulation evident here shows the need many persons with tremor have for assistive handwriting devices or substitutes for handwriting.

CONCLUSION

The limiting frequency, or bandwidth, for upper-extremity motion by healthy persons is approximately 2 Hz. Factors such as age and movement disorders may decrease this value. Frequency limitations on accuracy of upper extremity motion may limit the performance of man-machine interfaces such as assistive computer interfaces for the disabled.

Movement disorders can be seen not only to decrease overall motion accuracy, but also to change the relative levels of accuracy attainable by different types of motion. While healthy subjects generated motion most accurately with a pen, it was the worst device for accuracy by tremor subjects. A significant need therefore exists for devices to aid or supersede handwriting by persons with tremor.

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AN INSTRUMENT FOR TESTING AIMED MOVEMENTS AND APPLIED FORCES

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ABSTRACT

Two disadvantages of systems for studying aimed movements are the lack of hardware versatility and their nonaccommodation to the physical limitations of motorically disabled subjects. A general automated system was designed and fabricated to overcome these limitations. The design goals were to provide a user programmable means of generating an audible tone and multiple types of target displays (shape, position, and timing) on a working surface (15.5 x 23.5 inches) which is adjustable from 0^o to 90^o. The system's work surface needed to provide a means of recording the force applied, the position of touch and a remote optical device (head pointer) with a spatial resolution of 0.5 inches. The results of the tests with a disabled subject show that the system meets these goals.

BACKGROUND

Specialized equipment has been developed for studying the aimed movements of able-bodied humans and nonhuman primates. The instrumentation is usually designed to answer questions derived from specific theoretical frameworks which limits the adaptability of the instruments.

For instance, Soechting et al. (1) used instrumentation to derive a model of joint angle movements in space. The Subject moved the hand in geometric shapes in free space. The position of the elbow and of the wrist in space was obtained by a pair of ultrasound emitters and a set of three orthogonal, linear microphones. In addition, elbow angle of flexion-extension was measured goniometrically. Georgopoulos et al. (2) used a system to investigated the factors that influence the spatial characteristics of aimed movement trajectories of male rhesus monkeys. The central 9.8 by 9.8 inches of a plane surface served both as a display and as a working surface over which the animal moved a manipulandum. Nine light-emitting diodes (LED's) were used as targets. The manipulandum was a handle that the animal grasped and moved over the working surface. Shaft angle encoders measured the two angles of the manipulandum.

Problems with using the instrumentation previously described in studying subjects who are motorically impaired include the following. The first system (1) was unable to display targets; it used a goniometer and emitters which added load to the subject's arm. The second system (2) was limited to displaying nine target locations of a fixed shape and required a subject to grasp a manipulandum. Neither system measured applied force, provided for remote target manipulation, produced an audible tone, sensed the condition of an external switch or provided for user programming.

STATEMENT OF THE PROBLEM

If aimed movements are to be studied in motor disabilities, there are some constraints on the type of equipment which can be used. The system must not interfere with the subject's movements either by adding load or restricting arm motion in any plane. It should not require consistent grasp capability or prolonged pressing of a switch. Further the target array must present targets of any shape, at any position, and at a time defined by a user generated program. No system was found that could meet all of these design requirements.

RATIONALE

In order to overcome the problems in using existing system designs to study and assess aimed movement, a unique system was developed (3). The goals for this system are given as follows.

The system had to display targets. The system had to automatically control both the time at which a target is presented and the position of the target on the working surface. Geometric arrays (including alphabetical characters) had to be available as targets.

The system had to sense an object (e.g., arm/hand) on a two dimensional plane without adding load to the arm/hand. The spatial resolution of the position sensing system had to be at least 0.5 inches with a temporal resolution of 20 ms (sampling rate of 50 Hz). The work area had to be at least 15.5 inches high and 23.5 inches wide and had to be adjustable from 0^{o} (horizontal) to 90^{o} (vertical). The working surface had to sense an applied force. The targets on the working surface had to be capable of activation by a system using a remote optical device (head pointer).

The status of an external switch had to be monitored to provide for manual target activation. All relevant events, including position of contact, condition of switch, applied force, and head pointer position had to be recorded on disk for future analysis.

The instrument had to be capable of generating an audible tone as well as sending seven bit ASCII information to a computer input emulating interface. The system had to be programmable by the user and it had to perform self diagnostics and report any errors to the user.

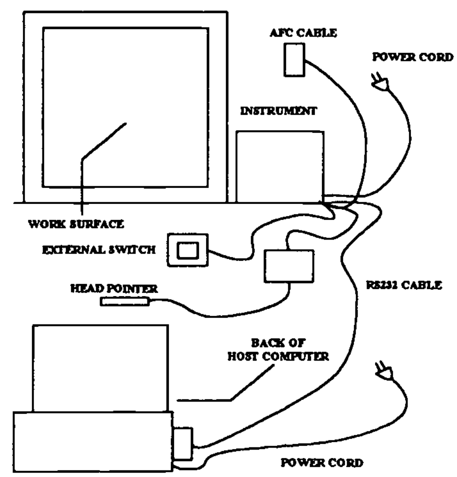
DESIGN

The system consists of an instrument, a host computer, host computer software and an optional computer containing a computer input emulating interface which allows the instrument to send signals to the computer as if the signals were typed from the computer keyboard.

The instrument consists of a display assembly, force measurement system, an instrument computer, power supplies, an interface cable, a communication (RS232) cable, an external switch, an optical head pointer (which allows the display assembly to determine the direction in which the head pointer is aimed), and system software.

The display assembly consists of a matrix of 1,536 LED's and the associated electronic steering driving circuitry. The force on the working surface is determined by measuring the sum of the signals from three bipolar strain gauges which support the working surface. The instrument computer is based on an Intel 8088 CPU running at a clock speed of 8 MHz. The position of an object on the working surface is determined by measuring the state (blocked or not-blocked) of infrared emitter detector pairs positioned around the perimeter of the work surface. The optical head pointer position is determined by sequentially illuminating the LED's on the work surface while measuring the response of the photo diode in the head pointer.

The function of the system is to present a stimulus in the form of an illuminated target or an audible sound and to record the pertinent data of a response in the form of a position profile on the work surface, a force applied to the work surface, and/or a logged event. A text file located on a host computer controls the way in which the system operates.



SYSTEM LAYOUT

Two sets of software were written for the system. The first set operates the host computer and the second set operates the instrument controller. The host computer software provides the interface for the user of the system. It translates a program file into a set of binary arrays that can be interpreted and executed by the instrument software. It also translates the data the instrument has recorded into an ASCII text file which is sent to the screen (in diagnostic mode) or to a disk drive following a program execution. The host software is written in C.

The instrument software operates the instrument as defined in the user generated program file. This software records the data and transfers the data to the host software. The instrument software also has a set of routines to perform a self diagnosis of the instrument. The instrument software resides in the instrument ROM and is written in ANSI C and assembly language.

A user generated program file defines how the instrument is to operate. The program file is an ASCII text file that is generated from a text editor such as WordPerfect. Data manipulation programs, written in C, were also developed to extract specific information, e.g., times between events, from a data file stored on a disk drive.

DEVELOPMENT

The original system design was laid out in a schematic capture program. System modules were assembled on wire wrapped boards and tested individually. Problems with the design such as an insufficient range of the position sensing system were corrected and the schematics were revised. Artwork was generated from the schematic files and printed circuit boards (PCB's) were fabricated from the artwork. The system hardware was assembled and tested. Problems with the hardware such as faulty wire connections were corrected. The System Software was then developed on an IBM PC. Final testing and modification to the integrated software and hardware system were completed with the use of an 8088 emulator.

EVALUATION

The system was tested to determine if the system goals were met. The system was tested with one subject, an adult female with a motor disability. The three types of tests performed were target display and position sense tests, a head pointer test, and a force sense test. The data from the pilot study tests were stored on a disk at the end of each experiment by the system host computer. The data on this disk were analyzed by an IBM PC using three data manipulation programs.

The results of these tests showed that a 1 inch square target was displayed following a switch closure. The system automatically controlled the time the target was presented and the position of the target. The first three letters of the alphabet were also displayed on the working surface. Making contact inside the target area caused the target to turn off, a marker number was recorded, and a momentary audible tone was turned on. The system sensed the position of a foam pad on the working surface in x and y coordinates with a spatial resolution of 0.5 inches and a temporal resolution of 50 Hz. The proper signals on the computer interface cable were verified on an oscilloscope. Position contact data, the status of a closed switch, the force applied to the working surface, and head pointer position were recorded on disk. A system self test was also successfully performed.

DISCUSSION

The results of the three types of tests performed in the pilot study show that the system meets the required design goals. The system has recently been used in a study of adaptation to the doll reflex in wheel chair athletes. The system should be useful in both basic and clinical research and in assessing the physical skills necessary for augmentative communication.

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THE COMPARATIVE EVALUATION OF ISOTONIC AND ISOKINETIC MODES OF TESTING WITH ERGONOMIC AND REHABILITATION PERSPECTIVE

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Abstract

The climbing costs of musculoskeletal injuries, and the implementation of the Americans with Disabilities Act create an increasing need for ergonomists and clinicians to develop effective means to assess the feasibility of performing a task. It is important to develop a unified approach to quantification of job demand and functional capability profiles. The objective of this work was to develop a data base of functional capability in terms of isokinetic and isotonic strengths for multiple joints. Ten subjects performed a variety of multi-joint strength and speed tests in the isometric, isokinetic and isotonic modes. The results show that the isokinetic mode is a more systematic and efficient method of characterizing the strength capability. The tradeoff between efficiency of tests and simulation of functional attributes of physical activity requires further exploration.

Introduction

Musculoskeletal injuries, of which low back pain constitutes the largest portion, are the second most frequent cause of worker disability, following cardiovascular diseases. According to the bureau of labor statistics, back injuries account for approximately 32% of all occupational disability injuries and consume up to 42% of all compensation payments (1). Ergonomists and researchers look for ways to quantify the feasibility of performing certain job tasks as related to individual functional capability. The Americans with Disabilities Act (ADA) Of 1990 dictates that employers must provide reasonable accommodations, which are not an undue hardship, so that any individual with disability can perform the essential function of a job. Potentially qualified disabled individuals must undergo a series of medical examinations to demonstrate the ability to perform the required job function. This creates a need to develop effective means to assess feasibility of performing a task by a unified approach to quantification of job demand and functional capability profiles.

Ergonomic evaluation of task demands could be used to provide the required torque and velocity at specific joint positions. This may be obtained from biomechanical multi-link models of lifting tasks. (2), (3), (4). The question whether a subject/patient (an applicant for a given job or an injured worker) can perform the analyzed task in terms of its basic elements of performance (i.e. strength, range of motion, endurance, speed, etc.), is the fundamental challenge in rehabilitation engineering.

In his paper about muscular performance evaluation, Sapega (5) reviews the evaluation of functional performance based on isometric or isokinetic modes of testing. Despite the fact that isometric and isokinetic test modes are known to be less functional as compared to dynamic daily activities, they have been extensively used in clinical evaluation (6). Up to date, there has been no study that compares the feasibility of performing a specific task in isokinetic and isotonic modes. Therefore, the objective of this study is to develop a data base of functional capability in terms of isokinetic and isotonic strengths for multiple joints. Additionally, the psychometric attributes of these two dynamic modes of testing will be compared.

Methods

Ten healthy male normal subjects participated in this study. The mean (s.d.) age, mass, and stature of the subjects were 26.2 (3.8) years, 85.1 (14.0) kg, and 178.6 (10.7) cm, respectively. The strength and speed of the subjects were studied for each of the isolated joints: elbow, shoulder, back. hip, knee, and ankle using the KIN_COM 125E Plus muscle testing and training system from Chattecx. corp. Each joint was tested using the isometric, isokinetic, and isotonic modes of testing. In the isometric testing mode, the subjects were asked to use maximum exertions at hold angles covering the range of motion for both extension and flexion. During the isokinetic mode, the subjects were instructed to perform maximum exertion at each specific set velocity. These speeds were selected based on the values from literature as well as the results of the coordinated lifts performed in a previous study (3). During isotonic tests, the joint velocity and torque were measured while the resistances were fixed. Both the velocities and the

Table 1. The mean, maximum, and minimum measured torque during isotonic knee extension at specific joint positions and velocity range.

Velocity (deg/s)	Positions (deg)						
	110-119	120-129	130-139	140-149	150-159	160-169	170-180
0-25	14 ° 171.1 * 80.0 † 267.0 ◊	N/A	N/A	N/A	N/A	N/A	11 20.8 86.0 71.0
25-75	53 195.2 98.0 296.0	N/A	N/A	N/A	N/A	N/A	41 75.8 20.0 181.0
75-125	56 203.4 102.0 294.0	2 241.0 235.0 247.0	N/A	N/A	N/A	N/A	30 142.6 70.0 217.0
125-175	14 188.7 117.0 294.0	44 222.8 136.0 291.0	3 247.7 245.0 252.0	N/A	N/A	N/A	18 177.6 13410 228.0
175-225	N/A	24 223.0 136.0 291.0	3 247.7 245.0 252.0	N/A	N/A	N/A	21 158.1 92.0 219.0
225-275	1 168.0 168.0 168.0	27 214.4 145.0 291.0	6 259.7 226.0 292.0	2 261.0 261.0 261.0	N/A	N/A	12 175.0 152.0 219.0

Table 2. The mean, maximum, and minimum measured torque during isokinetic knee extension at specific velocity and range of joint position.

Velocity (deg/s)	Positions (deg)						
	110-119	120-129	130-139	140-149	150-159	160-169	170-180
10	179.6 * 76.0 † 251.0 ◊	203.7 159.0 250.0	204.5 171.0 243.0	204.0 177.0 254.0	208.2 157.0 253.0	191.6 158.0 235.0	161.6 109.0 164.0
50	102.2 46.0 160.0	151.5 93.0 187.0	174.4 143.0 205.0	195.4 166.0 219.0	220.0 188.0 251.0	227.8 210.0 258.0	170.7 105.0 211.0
100	81.9 43.0 108.0	110.2 80.0 140.0	133.1 110.0 158.0	150.5 129.0 182.0	168.9 144.0 200.0	193.1 164.0 230.0	168.8 105.0 198.0
150	60.2 27.0 97.0	94.9 54.0 116.0	127.8 116.0 148.0	146.9 113.0 178.0	168.1 114.0 228.0	177.6 137.0 224.0	152.2 96.0 194.0
200	71.8 43.0 91.0	125.4 48.0 177.0	172.1 110.0 216.0	199.1 148.0 251.0	218.5 159.0 269.0	215.9 183.0 247.0	146.0 121.0 159.0
250	132.3 83.0 190.0	142.0 96.0 200.0	114.4 93.0 156.0	236.0 236.0 236.0	120.0 120.0 120.0	112.2 98.0 161.0	N/A

° : Number of observations, * : Mean torque, †: Minimum torque, ◊ : Maximum torque, N/A : No data were present in these specific cells resistances used were joint-specific. The knee velocities, for example, were 10, 50, 100, 150, 200, 250 Degrees/s; in the isotonic mode, the resistances of the knee joint were 10, 50, 100, 150, 200, 200 Newtons.

Results

The descriptive and distribution profiles were obtained for each joint. For the purpose of illustration, the results are shown based on the isotonic and isokinetic knee extension for one subject. Table 1 shows the mean, minimum, and maximum measured torque (Newton-meter) at specific joint position and velocity ranges during isotonic mode of testing. Table 2. shows the mean, minimum, and maximum measured torque at specific isokinetic velocities and position ranges during isokinetic testing.

Figure 1. represents an example of a bivariate distribution histogram for each combination of ranges of joint velocities and positions.

Discussion

It can be seen from the tabular and graphical results that although a wide range of resistances were used during the isotonic exertions, the final matrix is rather square as compared to the isokinetic data. Hence the proposed question cannot be evaluated for those combinations of joint velocities and positions that were not represented in the data base. This indicates that the isokinetic mode of testing in the evaluation of muscular performance is a more systematic and efficient method of characterizing the strength capability. This study does not answer how the isokinetic mode compares with unconstrained dynamic activities in terms of functionality.

In conclusion, despite acknowledging that the isokinetic mode may not be functional, tradeoff between efficiency of tests and simulation of functional attributes of physical activity requires further exploration. Additionally, future studies should consider the recruitment patterns during these modes of testing to farther delineate task appropriateness of these tests with respect to unconstrained dynamic tasks (i.e. lifting).

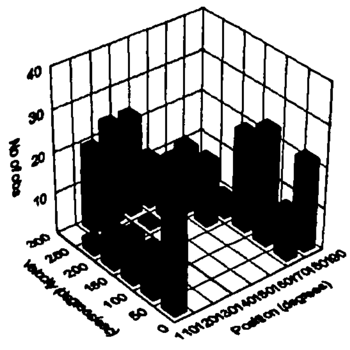

Figure 1. Bivariate Distribution Histogram of isotonic knee extension for one subject

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A VALIDATION STUDY OF A LIFT SIMULATOR DURING ISOINERTIAL LIFTS

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Abstract

Dynamometers are being used increasingly in the rehabilitation field to quantify the disability of injured workers and to train them for their return to work. However, the exercises performed with these dynamometers have not been shown to be functionally equivalent to their real world counterparts. Hence no information can be inferred from such exercises. A comprehensive set of lifting exercises was developed to validate the isoinertial mode of the LIDOLift lifting simulator (Loredan Biomedical, Inc., Davis, CA). Ten subjects performed a variety of submaximal and maximal lifts in the isoinertial mode. The data from the submaximal lifts were used in a linear regression to quantify the behavior of the isoinertial mode. The submaximal lifts at higher loads were found to more accurately represent the theoretical behavior than the lifts at lower loads. Overall, the R^2 value for the measured and predicted loads was .96. When the coefficients from the regression of the submaximal lifts were used for the regression of the data from the maximal lifts, the predicted forces were within 5% of the measured forces, $R^2 = .915$.

Introduction

The measurement of muscular performance has become a necessity in the physical medicine and rehabilitation community. Clinicians have used dynamometer-based systems for the purpose of rehabilitating the injured workers and athletes, and for objectively documenting the extent of disability for the resolution of legal disputes, the brunt of which are Workers' Compensation claims (1).

Objective quantification of trunk muscular performance is most significant since a majority of low back pain patients do not present any anatomical finding (2). A small portion of patients who become chronic are responsible for 80% of the total cost (2). Hence, quantitative assessments allow more precise evaluation of functional disability and provide processes for early return to work. A major cost saving effort is directed towards management of acute low back pain to avoid the prospect of chronic illness (2),(3).

The importance of an objective means of quantifying muscular performance is further magnified by the enaction of the Americans with Disabilities Act (1991), which requires that muscle testing reflect the 'essential function of the task'. In addition, companies are obligated to provide 'reasonable accommodation' for the worker. The testing of the functional capabilities of the worker should play an important role in the interpretation of 'reasonable accommodation'.

Dynamometers are a preferred tool for muscle testing and rehabilitation because of their safety and objectivity compared to manual testing. However, the inference of functional capacity by the use of any of these dynamometers has remained controversial (1),(4). Consequently, it is essential that these machines are proven to be valid in their simulation of real world, or free dynamic, activities.

The LIDOLift (Loredan Biomedical, Inc., Davis, CA) is a computer-controlled lift device that is supposed to simulate isometric, isokinetic and isoinertial lifting conditions. The calibration of the electromechanical sensors and the validation of the LIDOLift in the isometric and isokinetic modes has been shown by Wright *et al.* (5). However, the validation in the isoinertial mode has not been reported in literature. The purpose of this paper is twofold. First, a model will be developed that describes the behavior of the LIDOLift in the isoinertial mode. Secondly, the model will be used to predict the behavior of the LIDOLift in subsequent testing procedures.

Methods

To determine the validity of the isoinertial mode, ten healthy male normal subjects participated in a study after signing a consent form approved by the human subjects committee. The mean (s.d) age, mass, and stature of the subjects were 26.2 (3.8) years, 85.1 (14.0) kg, and 178.6 (10.7) cm, respectively. Briefly, each subject lifted and lowered a two-handled box attached to the arm of the LIDOLift. The simulated masses for the study were 6.8, 13.6 and 20.5 kilograms (15, 30, and 45 pounds, respectively). A linear regression analysis was performed to find the best fit model for the measured force, based on:

$$F_m = c_1 \bullet m + c_2 \bullet m \bullet a \qquad (1)$$

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Table 1. Values of Coefficients and R^2 based on linear regression of measured force with the simulated mass, and mass times the acceleration (Equation 1).

Simulated Mass	COEFFICIENTS C1	C2	R^2
6.8 kg	6.23	1.18	0.89
13.6 kg	7.92	1.75	0.96
20.4 kg	8.45	1.08	0.98
All	8.13	1.26	0.96

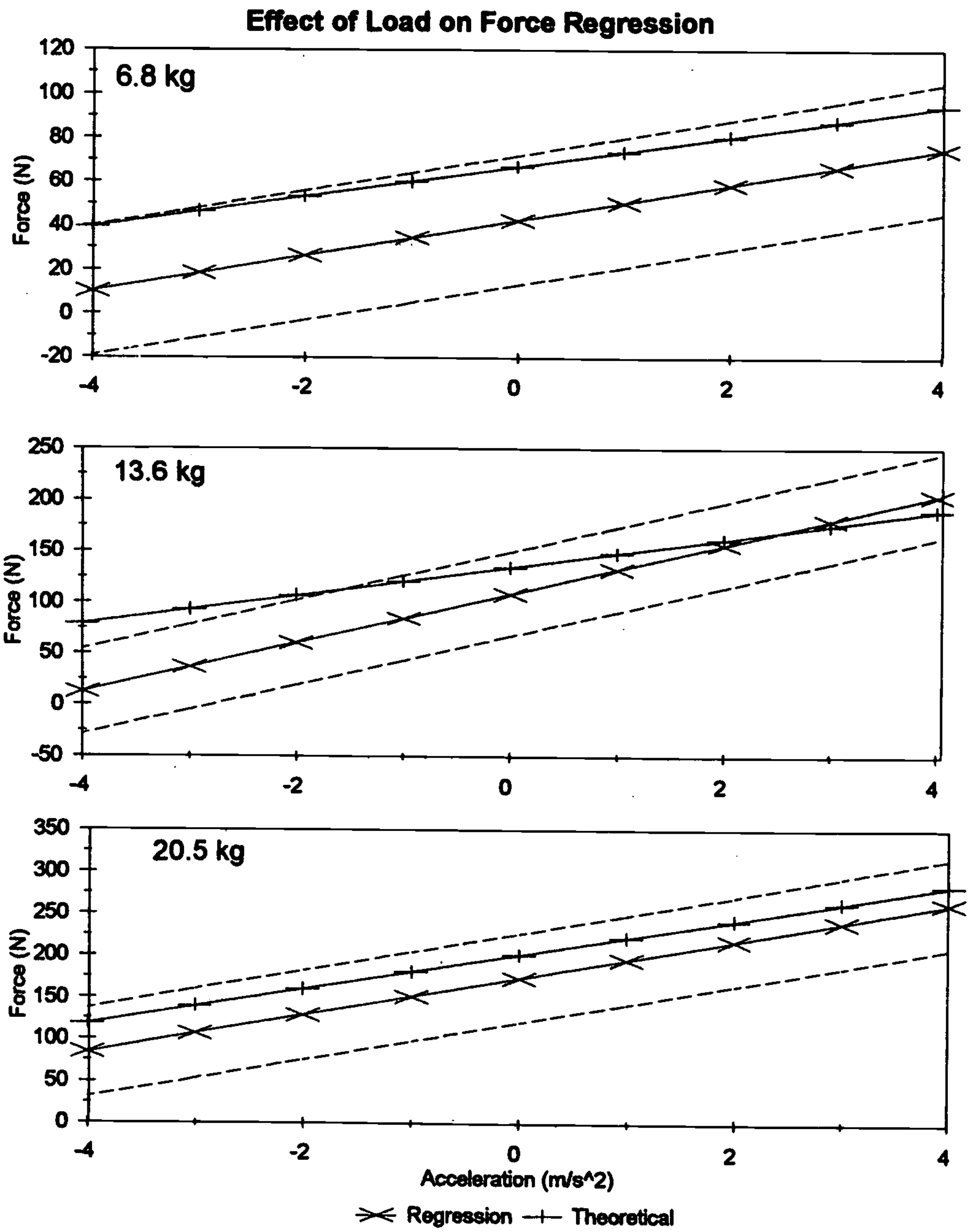

Figure 1. The effect of simulated load on the difference between the theoretical force and the measured force predicted by linear regression. Lines with (X) are from the regression. Lines with (+) are the theoretical forces. Dashed lines represent the 95% confidence interval for the regression line.

where F_m is the measured force, m the simulated mass, a the acceleration of the device arm, and the coefficients c_1 and c_2 to be determined by the regression. No intercepts were included in the model, hence facilitating a physical interpretation of the model. The theoretical force prediction based on an isoinertial mode of lift would require c_1 and c_2 to be equal to 9.81 and 1.0 respectively. Then c_1 would physically represent the gravitational constant for acceleration. The aforementioned regression was performed for each simulated mass and for the entire data set. A number of other regressions were performed that are not presented here.

Next, maximum isoinertial lifts were performed by each subject. The data from these lifts were input into the regression model (the right hand side of Equation (1)) to determine the predicted force. The simulated masses for the maximum isoinertial lifts ranged from 33.2 to 95.5 kg. An additional regression between the predicted force and the measured force from these independent lifts was performed.

Results

In the regression of the three simulated masses, the coefficients c_1 and c_2 and R^2 of the model, fit to each mass separately as well as fit to the whole data set, are shown in Table 1. As the mass increases, R^2 increases. In addition, coefficient c_1 approaches the value of 9.81 as the simulated mass increases. Coefficient c_2, approaches the value of 1.0 at the highest simulated mass.

Figure 1 shows how the regression compares to the predicted at each of the loads. The marked lines represent the theoretical force (+) and the predicted force (x) based on the regression. The dashed lines are the 95% confidence intervals for the predicted force. As the load increases from 6.8 to 20.5 kg, the simulated force line approaches the theoretical force line. However, the deviation of the slopes at 13.6 kg calls for caution against extrapolating any information beyond the values presented here. The theoretical force, based on c_1 equal to 9.81 and c_2 equal to 1.00, is within the 95% confidence interval for simulated loads of 6.8 and 20.5 kg.

For the maximum isoinertial lifts, the regression was performed with the coefficients from the whole data set ($c_1 = 8.13$, $c_2 = 1.26$). When these coefficients are used to predict the behavior of the LIDOLift during the maximum isoinertial lifts, the difference between the measured force and the predicted force is approximately 5% ($R^2 = .915$).

Discussion

The results indicate that the simulated mode is not exactly isoinertial at lower loads. However, the added safety provided by the simulator may outweigh this limitation. Clinicians and users of the product must account for this when planning a testing or training protocol. At higher loads, the simulated isoinertial conditions are much closer to the theoretical predictions.

It is intended that this research will lead to a cooperative effort between the developers and users of similar products, so that the training and testing protocols used in the rehabilitation field may undoubtedly reflect the activities in real world environments. Based on these results, we are initiating another study to help setting the simulated mass so that the current limitations can be compensated.

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THE EFFECTS OF LOAD, MODE, SPEED OF LIFT ON THE POWER GENERATION, ABSORPTION AND TRANSFER DURING A MULTI-LINK COORDINATED LIFTING TASK

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Abstract

The reduction of the large costs associated with the chronicity of low back pain is a driving force in the development of strategies to rehabilitate the injured worker. Quantitative assessment of the demands of the job along with the functional evaluation of the patient provides a rational basis for the process of the return to work. Ten subjects participated in a study to determine the power requirements of several lifting tasks and to analyze the effect of lift parameters on these power demands. The hip was found to provide most of the power generation in the lifts, while the most power transfer occurred in the back. The economy of movement was approximately 0.26 throughout the time of lift. An ANOVA revealed that a stoop lift is the least demanding in terms of econmy of movement. It is concluded that the power analysis is a necessary tool to complement the information given by an examination of external moments, since the former naturally reflect the dynamic parameters of performance (i.e. velocity and acceleration) which have been implicated as potential risk factors.

Introduction

It is recognized that the timely rehabilitation of the worker with a lower back injury is paramount in the prevention of the chronicity of low back pain. Because disability associated with chronic low back injury is implicated with a large amount of the health care costs (1), it is important to develop strategies for rehabilitating the injured worker quickly.

The quantitative assessment of job demands and functional testing of disability are needed to determine a training protocol that will return the injured to work as soon as possible. For example, if the biomechanical analysis indicates that a hip power generation of 425 Watts is required during a lift of 20 kg., and the injured worker is unable to meet this task demand, the goal of the rehabilitation program is directed to enable the worker by strengthening exercises and/or use of optimal lifting techniques.

The analysis of power requirements of the joints and the relative sharing of power amongst the joints in performing a task has been proposed as a method for job demand assessment (2). Moreover, the patterns of joint generation, absorption and transfer produced in a task may lead to a better understanding of the load sharing during multi-link coordinated lift, which may help to distinguish between the patient and normal population.

The purpose of this paper is to present the power analysis of a lift and then to detail the effects of different job demands on these power computations.

Methods

Ten healthy male normal subjects participated in a study after signing a consent form approved by the human subjects committee. The mean (s.d) age, mass, and stature of the subjects were 26.2 (3.8) years, 85.1 (14.0) kg, and 178.6 (10.7) cm, respectively. Briefly, each subject performed lifts involving three different loads (6.8, 13.6, and 20.4 kg), three different lifting modes (preferred, stoop, and squat), and three different lifting speeds (slow, medium, and fast). A more thorough description of the lifting protocol and analysis of data appears in Sparto *et al.* (3). The computation of power generation, absorption, and transfer is given by Robertson and Winter (4), while the economy of movement is described as the ratio of power transferred relative to the total power (i.e. generated + absorbed + transferred) (2).

Results

The results of a lift at 20.4 kg, preferred mode of lift, and fast speed for one subject is shown in Figure 1. The pattern of these curves is consistent for all subjects.

The joint positions are shown in Figure 1-A, with 0 degrees representing full flexion and 180 degrees full extension of each joint. The hyperextension of the hip and the motion of the L5/S1 joint are calculated based on the measured value of the knee and trunk angles, using the regression equation reported by Chaffin and Andersson (5). The trunk angle is also shown so that the motion of the whole body can be better described.

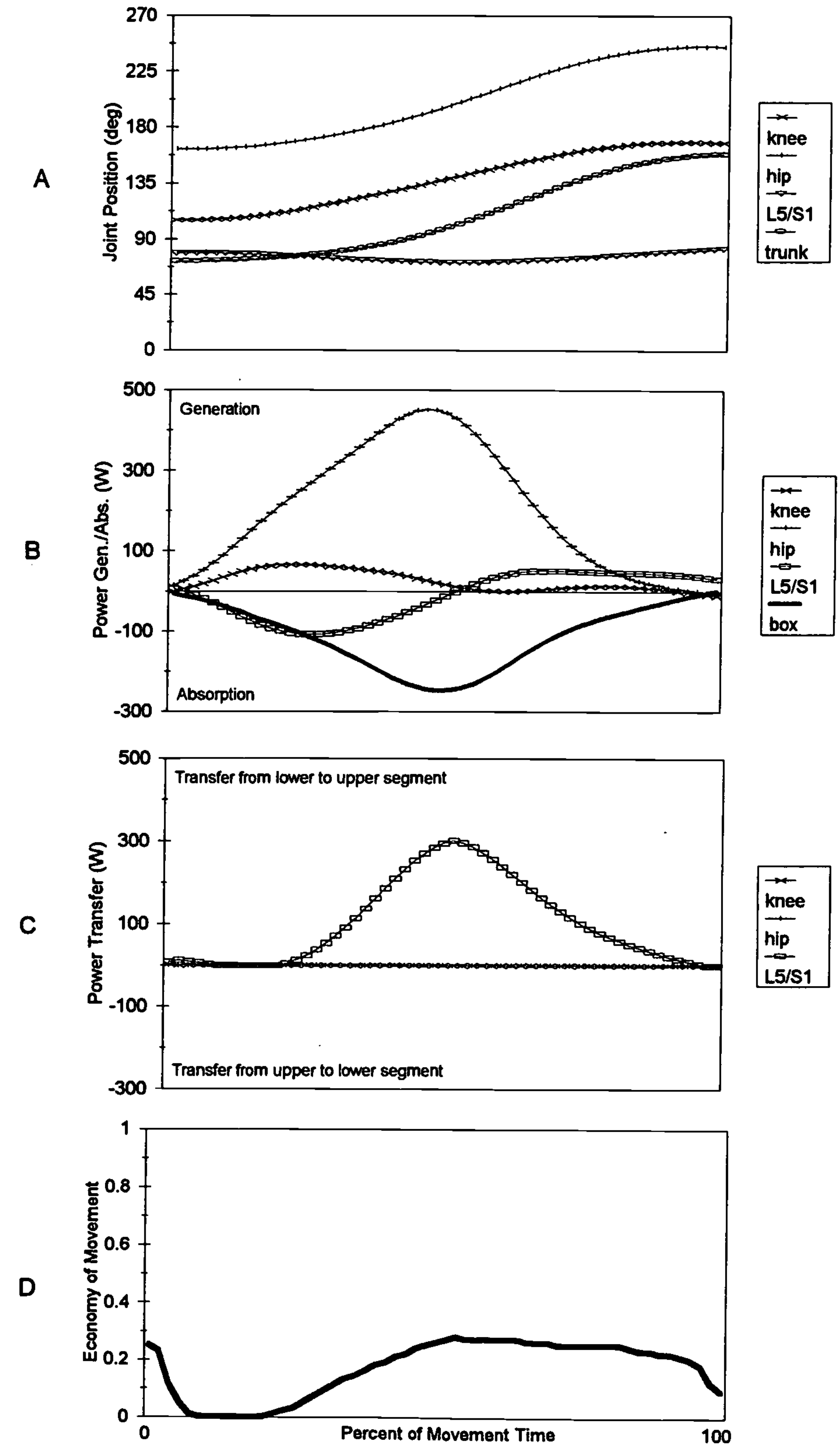

Figure 1. The joint position (A), power generation and absorption (B), power transfer (C), and economy of movement (D) of a lift of a 20.4 kg. load at a fast speed in a preferred lifting mode by one subject. For the joint position, 0 degrees is fully flexed and 180 degrees is fully extended.

Table 1. The summary results (p-values) of ANOVA, testing the effect of load (L), mode (M), speed (S), and their interactions on the energetic parameters during a lifting task. An asterisk indicates significance, $\alpha=0.05$.

	P-values of the effect of:					
Dependent variables	L	M	S	L X M	L X S	M X S
Knee power gen. / absorption	0.040*	0.0003*	0.0001*			0.0001*
Hip power gen. / absorption	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
L5/S1 power gen. / absorption		0.0001*		0.0001*		0.0001*
L5/S1 power transfer	0.0001*	0.0001*	0.0001*		0.0001*	0.0005*
Economy of movement	0.0001*	0.0001*	0.010*			

The patterns of power generation, absorption, and transfer, shown in Figure 1-B, and 1-C should be considered together when analyzing the data, since the sum of power at each joint is divided into the generation or absorption by muscles spanning the joint, and transfer from the one of the segments of the joint to the other. The muscles of the knee and hip are generating power throughout the whole lifting phase, while generally there is little or no transfer. The trunk muscles are initially absorbing power and then generating power, while a transfer of power from the muscles of the pelvis to the back is occurring from 25% of the movement time to the end. Additionally, the power transferred to the box is shown in Figure 1-B.

Clinically, a more useful description of the data might lie in the economy of movement, an example of which is shown in Figure 1-D. The value of the economy during most of the cycle is approximately 0.26. Meanwhile, the value of the economy in the initial portion of the lift should be considered with caution due to the small magnitude of the power terms.

The results of the ANOVA of the effects of load, mode, speed, and interactions is detailed in Table 1. There is a highly significant difference between modes of lift for all five variables presented here. The results from a Tukey post-hoc analysis show the power generation of the knee and hip muscles to be less for a stoop lift than the other modes of lifts. Additionally, the economy of movement is greatest for the stoop lift, while the economy of the preferred lifting method is greater than the squat lift. This result is consistent with physiological findings (6).

Discussion

The complete power analysis described here is currently being used as a tool for the assessment of the demands of the job. When the power demands are compared with a clinically-based strength and power evaluation, a viable rehabilitation program can be developed. In addition, task analysis and functional evaluation protocols based on the power requirements reflect the dynamic components of physical activities much better than the quantification of external moments alone.

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SIG-06
Special Education

EDUCATION AND ASSISTIVE TECHNOLOGY: FLORIDA'S MODEL

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In response to federal requirements and ongoing demands for assistive technology services, the Florida Department of Education, Bureau of Exceptional Student Education, has implemented a statewide plan for providing service, technology and training to its entire exceptional student school aged population. Built upon a foundation of existing specialized support services, the state initiative involves four main components: regional resource centers, a network of local assistive technology specialists, a device loan library, and a personal device loan system.

BACKGROUND

In response to federal requirements and ongoing demands for assistive technology services, the Florida Department of Education has implemented a statewide plan for providing technology and training to its entire exceptional student school aged population. The Department of Education stands as an integral member of a cooperative interdepartmental state venture to provide a seamless system of service, technology delivery and training to all its citizens with assistive technology needs.

OBJECTIVE

To unlock human potential by providing services to support and facilitate quality instruction for students with disabilities by providing assessment, equipment, and training.

APPROACH

Built on a foundation of existing specialized support services, the state initiative was conceptualized as follows:

1) THE ASSISTIVE TECHNOLOGY EDUCATIONAL NETWORK OF FLORIDA
ATEN serves as the statewide coordinating unit for assisting school districts in provision of assistive technology serves for Florida students with disabilities. The center, based in Orlando, serves as a model for four additional resource sites to be established over the next five years. ATEN provides assessment, technical assistance, training, reference library, newsletter, and an assistive device laboratory and loan system.

2) LOCAL ASSISTIVE TECHNOLOGY SPECIALISTS
A front line or triage resource for Florida's 67 school districts is provided through the combined efforts of the:

- Instructional technology staff of the 18 Florida Diagnostic and Learning Resource Centers (FDLRS) and
- Designated Local Assistive and Augmentative Technology Specialists (LATS)

who provide support and resources to educational programs of students using assistive technology. ATEN sponsors ongoing continuing education training and consultation to the cadre of 140 LATSs.

3) DEVICE AVAILABILITY
A short term device loan library serves as an assistive device resource for student evaluation and trial use. ATEN manages all maintenance, repair and shipping.

4) PERSONAL STUDENT DEVICE LOAN
A long range goal of the state initiative is the institution of a personal student device loan program, making any assistive technology available to a student free of cost when it is necessary for them in order to participate in a free and appropriate public education. Guidelines have been established defining the funding responsibilities of the individual schools and the state sponsored technology loan pool.

DISCUSSION

This project has finished its first year. While the personal student device loan program is still awaiting funding, the other components are fully operational. Community awareness workshops have been presented throughout the state, in addition to training modules on assessment and funding. Voice output, written output, computer access, light/low tech, vision, hearing, switch interface, mounting, and environmental control devices are available for short term loan. The final projected outcome of this venture is that each student will acquire the resources and skills necessary to reach his or her greatest level of achievement, independence and productivity in the community.

ACKNOWLEDGEMENTS

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ACCESS: SPECIAL EDUCATORS ON LINE

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ABSTRACT

The ACCESS Bulletin Board, established in January, 1986, links special educators throughout the state. Averaging over 30 calls per day, it serves as a communication vehicle and training device for professionals interested in the instruction of students with disabilities.

BACKGROUND

Over half of Michigan's special education students reside in the Metropolitan Detroit area, which includes Wayne, Oakland, and Macomb counties. In less populated, rural areas of the state, students and professionals who work with them are distributed over a wide geographical area. Personal communication between professionals dealing with similar populations is limited. In the less urban areas, professionals typically serve a diverse population and opportunities to learn about advances in new instructional methodologies, such as applications of assistive technology, are restricted by weather, distance, and available finances.

OBJECTIVE

Project ACCESS was established in 1983 as a State Initiated Project by a Michigan Board of Education grant under P.L. 94-142. Project ACCESS had two primary goals: (1) to provide support and assistance to districts in the instructional applications of technology for special education students; and (2) to provide support and assistance to districts in the use of technology for the management of special education data and planning and monitoring requirements.

Three basic approaches to providing information and technical assistance have been used:

1. A newsletter, distributed to some 18,000 members of the special education professional community in Michigan, was produced bimonthly from 1984 to 1993.

2. A series of training workshops and demonstration labs, and a toll-free "hot line" for technical help, have been provided continuously for the past nine years.

3. An electronic bulletin board system has been operating since 1986 to provide training and communications options for the special education community.

APPROACH

The electronic bulletin board service (BBS) has been operating since January of 1986. The board has five incoming lines which operate simultaneously (one toll free and four regular lines). The BBS has received a total of over 27,000 calls since beginning, and currently handles approximately 20 calls per day, seven days a week.

The BBS uses multi-tasking software ("The Chairman") so that several users can be on-line at the same time.

Present features of the ACCESS BBS include such public message boards as:

AER - Messages dealing with visual impairments
CALENDAR - Upcoming events, workshops, etc.
JOBS - Special education positions available in Michigan
OUTCOMES - Messages from the special education Outcomes Training Project
SIGSPED - An area for communication with the special education interest group of MACUL
TECHBORD - Messages regarding technology (help, hints, ideas, etc.)

In addition, the BBS permits establishing private conferences (accessible only by members approved by their respective group leaders) for groups such as:

MASP - Michigan Association of School Psychologists
MALDE - Michigan Association of Learning Disabilities Educators
MRS - Michigan Rehabilitation Services
COMPUTE - Coalition of Organizations in Michigan to Promote the Use of Technology in special Education

Facilities also exist for uploading and downloading of files, conducting surveys, and searching databases for resources and software titles.

Current expansion activities are focused on bringing larger databases (such as ABLEDATA) on line so those needing information about specific assistive technology devices can search for product names and producer contacts.

DISCUSSION

Three major uses of telecommunication have increased dramatically in the past few years:

1. Messages to individuals must be sent quickly and received when the recipient is ready.

2. Specifically formatted documents must be transmitted so that the receiver can review information exactly as it is intended to be seen.

3. Files must be sent so the receiver can capture them for further use on a computer (for word processing, data base manipulation and the like).

A number of methods have been developed to accomplish these communications, such as the digitized phone service for leaving and receiving voice communications and the fax machine for sending exact copies of documents. But to date the most readily available method for accomplishing all three of the above-mentioned uses is the electronic bulletin board system (BBS). Such a system allows users to send personal messages to each other, post public messages for all to read, send documents which can be "captured" by other users and printed, and send files to other users which they can capture for use on their own computers.

The ACCESS BBS has proven to be a cost-effective and viable means of communication between professionals who work with special education students. Its success is due to several factors. The toll-free number encourages use. The software itself is user-friendly, with extensive prompts in "novice" mode and more concise prompting when the user selects the "expert" mode.

At its inception, a small group of individuals with the equipment and background to learn how to use the system was available. More recently, feedback from professionals and observations of board use revealed several interesting facts. Although more special educators do have classroom computers, many teachers do not have telephones in their classrooms. The purchase of a modem must come from the teacher's supplies budget. Professionals unfamiliar with telecommunications require instruction and one-on-one support to use equipment and software correctly.

CONCLUSION

In 1993, the ACCESS Project relocated to a State Initiated Project which provides information, demonstration, and consultation services dealing with assistive technology for low-incidence populations.

The combined staff submitted and was awarded a grant to establish MATCH (Michigan Assistive Technology ClearingHouse), a component of Michigan's Technology-Related Assistance for Individuals with Disabilities Act of 1988. MATCH will include a State-wide electronic communication dealing with assistive technology; the ACCESS BBS will be used to facilitate the development of a system designed to meet the specific requirements which emerge during implementation. The current BBS also serves as a training opportunity for those wanting to learn how to use this growing method for exchanging information.

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TELEPHONE TECHNOLOGY FOR SENSORY INTEGRATION

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ABSTRACT

Using a telephone can be a formidable challenge for those with sensory integration issues. This paper discusses difficulties in using the telephone by a person with sensory integration issues. It discusses multisensory techniques and technologies to facilitate using a telephone.

BACKGROUND

Sensory integration theory is a concept developed by Dr. Jean Ayres.[1] The concept is that in some individuals a "traffic jam" can occur in the brain. A variety of sensory inputs can get "tied up in the traffic" of central nervous system processing.

Multiple body systems are affected. Auditory, visual, tactile, vestibular, and proprioceptive systems can all be involved. Sense of touch, movement, body position, organization of the senses, and motor planning can all be affected by integrative problems. Learning and many daily living tasks can be extremely difficult, if not impossible.

The Ayres Clinic in Torrence California is a rich source of information on sensory integration issues and therapy strategies.

IMPLICATIONS

Daily living tasks and stress increase integrative problems. Perceptual stress accelerates fatigue. Emotional reserves can quickly be depleted. Visual, auditory, and motor planning abilities are frequently over taxed. Perceptual and integrative problems can interfere with competitive use of the telephone.

THE PROBLEM

This author has a number of subtle, but highly significant, perceptual difficulties. Specific traits needing remediation are a severe figure-ground separation hearing loss (conductive mechanisms are within average limits), dyslexic inversions of digits, monocular vision, visual nystagmus, eye-hand coordination, and finger dexterity deficits.

These traits combine to make using the telephone a challenging task. Problems in using a telephone have occurred at home, work, and while traveling. Each poses it own unique circumstances and requires different remediation strategies.

Three specific at-home telephone tasks need to be addressed: 1) obtaining a phone number; 2) dialing a number; and 3) hearing through a telephone.

APPROACH

An eclectic, multidisciplinary approach was used to survey methods, equipment, and techniques. Simplicity, low cost, and ease of use of any strategy was required.

DISCUSSIONS AND SOLUTIONS

1. Obtaining a phone number.

The local telephone service (Ameritech) provides operator assistance for qualified individuals with disabilities. Use of this service eliminates visual and motor planning stressors involved in finding a name and phone number in a low contrast, fine print, phone book. It also eliminates visual focus, dyslexic transpositions, and motor planning problems when attempting to either write down the phone number or dial it directly.

Use of a phone book cannot be eliminated. Perusal of the yellow pages is a perceptually demanding task. Lighting techniques for low vision are excellent strategies for this low contrast reading task.

A lighted magnifier proves to be an invaluable tool for telephone book reading. A high intensity task light near the phone can assist with reading and also with seeing the telephone keys. Perski has published other excellent ideas for lighting techniques and low vision. [2]

2. Dialing.

For frequently called numbers, auto-dialers are invaluable. Ones that are built into a phone, as well as portable dialers and computer modems all help reduce motor planning and visual acuity demands. Finger dexterity and hand tremors almost become non-issues.

Manual dialing is a day-in and day-out task. Larger telephone keys increase the visual motor accuracy. They also minimize the coordination and tremor errors from hitting adjacent keys.

A phone that displays the numbers on a three-eighths inch display helps verify the digits as they are keyed. The display also has the advantage of retaining a number after it is dialed. In addition to instant feedback, it also gives a check in case of either a user or system error. This feedback helps with self-esteem and confidence.

A separate in-line speech synthesizer also helps with verification and in controlling the speed of input. The voice generator will not allow fast input of a number. It will only recognize and speak a number if the touch tone for a digit is a minimum electronic length for decoding. This design limit helps reduce motor planning errors by forcing a slower pace. If motor coordination is working well, inputing the phone number quickly makes the synthesizer transparent. This is a nice feature for others who use the phone.

Highest levels of successful dials are made by a) placing the display so it is directly in the center of the visual field, b) turning on the speaker without lifting the handset to get a dial tone (eliminating a motor planning task), c) placing the written number directly under the key pad, d) keying the numbers at a pace suitable for processing by the voice synthesizer and watching the numbers appear on the display.

3. Hearing.

Ambient background noise is an enemy to anyone with hearing difficulty. Noise in telephone calls can originate at the caller's location, in the phone wiring, or at the receiver's location.

Noise at the callers location:

This is easiest to control. Ambient noise is best kept to whisper-quiet levels. When this level is not possible, the ear that is not used to listen to the phone is plugged. This increases the signal to noise ratio and reduces auditory processing demands.

Plugging of both ears and using amplification to overcome the reduction by the occlusion increases the signal to noise ratios to very high levels. However. this type of boost makes perception of the low end of a speaker's dynamic range much more difficult. Clipping of the speaker's message is frequently a problem with this technique.

Amplification increases the signal strength. What works effectively is a combination handset and amplifier. A thumb wheel in the handset provides rapid and convenient adjustments that compensate for even the softest voices. Occasionally, a speaker will have an auditory projection that even with minimal amplification will cause excessive sound pressure levels. Holding the receiver slightly away from the ear easily deals with this rare dilemma. This type of handset also allows the use of long cord--a real plus when tight muscles need to be stretched.

Noise in the telephone wiring:

Each connection in a telephone circuit adds resistance. Resistances can combine to reduce signal strength. All phone lines are directly wired to the entrance panel.

Noise at the receiver's location:

People with average hearing can readily hear a speaker through typical ambient noises like washing dishes or with a radio playing. A simple request to eliminate the noise source will generally be honored. This reduces auditory fatigue. Similarly requesting the other party to use a handset rather then a speaker increases signal strength and reduces perceptual fatigue.

These strategies and technologies make using the telephone at home far less demanding. One thread of perceptual and emotional stress is dramatically reduced. By using these strategies and technologies, auditory and emotional reserves are increased.

TELEPHONE TECHNOLOGY, 3.

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ASSESSING PREDISPOSITIONS TO TECHNOLOGY USE IN SPECIAL EDUCATION: MUSIC EDUCATION MAJORS SCORE WITH THE "SURVEY ON TECHNOLOGY USE"

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ABSTRACT

Assistive and educational/instructional technologies have expanded the options for individual students. For students to avail themselves of the increased educational opportunities available to them, it is important that they become comfortable with these technologies. The **Survey of Technology Use** is discussed as a means of assessing individuals' predispositions technology use in general.

BACKGROUND

The **Survey on Technology Use (SOTU)** is a part of the **Matching Person and Technology (MPT) Model** and its purpose is to assess predispositions to technology use in general. Other assessments in the MPT Model are designed to assess the quality of match of a person with a specific type of technology (assistive, educational, workplace or healthcare). The SOTU is a self-report checklist of 29 items in four subscales: a) experiences with current technologies used (5 items), b) perspectives on new technologies (7 items), c) activities (4 items), and d) personal/social characteristics (13 items). All items are in a 3-point semantic differential format (for example, depressed, neutral, happy). A companion version (Technology Overload Assessment) exists for completion by professionals. One such group of relevant professionals is music education majors who will be teaching in mainstreamed schools. Music classes are popular with many students with disabilities; the classes are also using more computer software packages to teach rhythm, notation, etc.

RESEARCH QUESTIONS

1. How predisposed to technology use is a typical group of undergraduate music education majors?
2. How similarly can they rate a student's general predisposition to technology use?
3. How strong is the SOTU as a measure?

METHODS AND DATA SOURCES

Methods used to develop the MPT instruments have been described elsewhere. The methods and data sources described here are limited to information collected to assess the SOTU's inter-rater reliability and stability (test-retest reliability). The SOTU was created from the experiences of people who used or did not use a technology provided to them and, consequently, has <u>content validity</u>.

<u>Inter-rater Reliability</u>

Twenty-one music education undergraduate students in an educational psychology course at the Eastman School of Music/University of Rochester were shown a videotape of a student considering using a computer and completed the SOTU on that student. Item modes were calculated for all items and the difference between the mode and the individual raters' response was computed. Since only differences from the mode are of interest, the array of difference scores was used to calculate the "average difference score" or "average deviation from the mode." The resulting statistic reveals the number of raters who chose the same or similar response for a given item. The closer the average difference score is to zero, the more consistent were the raters' judgements of the characteristics.

<u>Stability</u>

Twenty-two of the music undergraduates completed the SOTU on themselves during the first and 14th week of the semester (January to May 1993). In January, only 22.7% rated themselves as having moderate-considerable exposure to computers; another 22.7% had no exposure to computers.

RESULTS

<u>Inter-rater Reliability</u>

Inter-rater agreement for the SOTU items is shown in the table on the next page.

SURVEY ON TECHNOLOGY USE

Reliability and Validity Data

	Case Inter-Rater Agreement (n=21)		Four Month Stability (n=22)
Item	% Agreement	Avg. Deviation from Mode	% Agreement from Time 1 to Time 2
Experiences with Current Technologies Used			
Socially Enhancing	81.0	.19	72.7
Satisfying	90.5	.10	90.9
Enhanced Creativity	85.7	.14	72.7
Encouraging	50.0	.50	81.8
Improved Self Esteem	90.5	.19	77.3
Perspectives on New Technologies			
Exposed			
- As Child	84.2	.21	68.2
- In Education	76.2	.24	63.6
- Recently	45.0	.55	68.2
Challenged	85.7	.19	50.0
Cognitive Approach: Logical	71.4	.33	57.1
- Comfortable with Equipment	100.0	.00	68.2
- Use of equipment has been Reinforced	100.0	.00	50.0
Activities			
Active (Sports/Walking)	95.2	.05	54.5
Hobbies (Satisfying)	47.6	.67	68.2
Group	66.7	.43	59.1
Seeks fresh, new activities	95.2	.05	81.8
Personal/Social Characteristics			
Composed/Calm	55.0	.45	63.6
Happy	60.0	.40	77.3
Tolerant	76.2	.29	63.6
Positive Outlook	42.9	.81	68.2
Expressive/Outgoing	61.9	.52	63.6
Patient	47.6	.52	72.7
Motivated	50.0	.50	68.2
Persevering	78.9	.21	59.1
Socially Active			
- Family/Spouse	50.0	.50	90.9
- Non-Family	81.0	.29	45.0
Good Sense of Well-Being	71.4	.48	77.3
Independent			
- Physically	66.7	.48	81.8
- Emotionally	70.0	.30	54.5

The first column gives the percentage of raters who gave exactly the same response to a given item on the first and second administration of the SOTU. The second column is the average deviation statistic described earlier.

Items related to the technology itself and its use received the highest consistency in ratings. Items concerned with user psychosocial characteristics received slightly less agreement scores.

Stability

The SOTU seemed to be reasonably stable over the four-month period for this group of students. The most stability was seen with items related to "Experiences with Current Technologies Used;" less with those items asking about "Perspectives on New Technologies Used." From Time 1 to Time 2, eight students reported being exposed to a new technology: 75% of those eight changed their ratings for "challenged" and "cognitive approach;" 50% changed their rating in "use of equipment has been reinforced." Change occurred over time in all students' ratings of their group activities and non-family social activities. Such consistency, the fact that these two items both changed, is positive.

CONCLUSIONS

Based on the data from this group of students, the SOTU seems to be a reasonably reliable instrument with adequate inter-rater and test-retest reliability. When asked to complete the SOTU for a videotaped student, raters displayed an 80% or higher agreement on more than 2/3 of the individual items. While not strictly speaking a highly computer literate group, the music education undergraduates were able to rate a potential student's predispositions to technology use quite consistently. When asked to complete the SOTU on themselves, test-retest stability was also relatively high.

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EXPLORING LEGAL RAMIFICATIONS OF THE APPROPRIATE APPLICATION OF ASSISTIVE TECHNOLOGY IN THE INDIVIDUALIZED EDUCATION PROGRAM

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ABSTRACT

Assistive technology (AT) is redefining educational opportunities for children served in special education programs. AT is being designed, developed and implemented for children with an increasingly wider range of cognitive and physical abilities and disabilities. In the classroom, AT is enabling students with disabilities more independence, self confidence, production, and integration into the mainstream of society (Lahm and Elting, 1989; Wilds, 1989). However, most Individualized Education Programs (IEPs) for students with disabilities are conducted in such a manner as to never address the need a student may have for assistive technology. This lack of appropriate applications of technology has serious legal ramification for those involved in developing and implementing IEPs.

BACKGROUND

It has been determined that consideration of a child's need for assistive technology must occur on a case-by-case basis in connection with the development of a child's IEP (Schrag 1990). The Code of Federal Regulations (34 CFR 300.346) states that a child's IEP must include "a statement of the specific special education and related services to be provided to the child". The above noted Schrag letter states that AT qualifies both as a special education service and/or a related service. The CFR (34 CFR 300.346) also states that the IEP must include "the extent to which the child will be able to participate in regular educational programs." The appropriate application of AT will likely be used in legally defining, and possibly altering what has historically been determined as, the least restrictive environment (LRE).

Assistive technology is destined to play an increasingly important role in the education of students with disabilities. The most recent amendments to P.L. 94-142 (IDEA) include definitions of an assistive technology device and assistive technology services. These definitions are taken from the Technology Related Assistance to Individuals with Disabilities Act of 1988 (P.L. 100-407).

Recent advances in technology and rehabilitation engineering have led to a dramatic surge of interest in the use of assistive devices, and in the commercial availability of equipment and devices designed for persons with disabilities. Assistive technology includes adapted toys, alternative input and output devices for computers, eating systems, powered mobility devices, augmentative communication devices, special switches, etc. Thousands of commercially available or adapted devices and solutions that improve a student's ability to study, learn, compete, work, and interact with family and friends, are now available. Access to technology promotes efficiency, increases accuracy and often acts as a sensory stimulation. However, for those with disabilities, it is a vehicle by which many obstacles can be circumvented and disabilities overcome (Fifield, 1990). In particular, access to technology advances holds great promise for enriching educational opportunities and effecting the lives of students with disabilities (Gradel, 1990)(Barker, 1990).

OBJECTIVE

The objective of this paper is to fully explore the current legal opinions and documents that have reference to the application of technology in developing appropriate IEPs for students with disabilities. A thorough examination is intended to result in greater understanding for parents, special educators, local education agencies and other interested parties as to what their role and responsibilities are in the IEP process.

APPROACH

Two major legal barriers to the appropriate application of AT for students with disabilities are: 1) the lack of information teachers, parents and student advocates have about the legal requirements concerning the application of AT in the provision of special education services; and, 2) inappropriate and possibly illegal IEP practices as they relate to assessment and meeting the individual needs of students. It is not possible at this point in time to differentiate the information pertaining to these two issues because statements and procedures address only the provision of special education services.

In addition to those references presented previously in this paper, assistive technology is referenced in IDEA rules and regulations as follows: Section 300.308 Assistive Technology. Each public agency shall ensure that assistive technology devices and assistive technology services, or both, as those terms are defined in §§ 300.5-300.6 are made available to a child with a disability if required as a part of the child's -

(a) Special education;
(b) Related services; or
(c) Supplementary aids and services.

The student assessment/valuation process, as outlined in P.L. 94-142, Section 300.532, states that " . . . the child is assessed in all areas related to the suspected disability, including, where appropriate, health, vision, hearing, social and emotional status, general intelligence, academic performance, communication status, and motor abilities." In addition to the traditional assessment and evaluation of students, the use of technology to facilitate maximum student potential needs to be considered (Bragman, 1987). Technological considerations augment the traditional evaluation by providing information about the student's ability to access and use technology.

In addition to legislative references to assistive technology found in IDEA and its accompanying rules and regulations, 3 policy letters have been issued for the Office of Special Education and Rehabilitative Services responding to inquires associated with the provision of assistive technology as part of special education service delivery. The first letter, August 10, 1990, is in response to an inquiry as to whether school can presumptively deny assistive technology to students and if assistive technology should be considered on a case-by-case basis in the development of a child's IEP. In reply Dr. Schrag states, "it is impermissible under EHA-B for public agencies 'to presumptively deny assistive technology' to a child with handicaps before determination is made as to whether such technology is and element of a free and appropriate public education (FAPE) for that child. Thus, consideration of a child's need for assistive technology must occur on a case by case basis in connection with development of the child's individualized education program (IEP).

A second letter for Dr. Schrag, November 27, 1991, address several additional question. The first question, and the one the pertains directly to assistive technology, is whether or not a child may access assistive technology for homework, reading books, and other assignments away from school. This determination is made by the IEP team. "If the IEP team determines that a particular assistive technology item is required for home use in order for a particular child to be provided FAPE, the technology must be provided to implement the IEP."

A third OSERS policy letter dated November 19, 1993 is in response to the following question: "If a students needs a hearing aid (assistive device) is the school district responsible for purchasing the device under the new IDEA if the device is put on the IEP?" The policy letter indicates that historically personal devices such as hearing aides were not covered. "However, this policy does not apply to a situation where a public agency determines that a child with a disability requires a hearing aid in order to receive a free appropriate public education (FAPE), and the child's individualized education program (IEP) specifies that the child needs a hearing aid." The letter continues with a discussion of assistie technology and it can be inferred that this policy applies to other assistive devices. Again, it the participants at the IEP meeting that determine the what the child requires in order to receive a FAPE. Accordingly, the public agency must make an assistive technology device or service available if such device is necessary for a child to receive a FAPE

DISCUSSION

1. Any participant in a IEP has the right to request that the IEP team consider the child's need for assistive technology as the IEP is being developed.
2. If the IEP team determines that the child may need assistive technology a part of the special education delivery, the LEA is responsible to provide the technology, including an appropriate assessment to determine what the need may be.
3. Assistive technology can be a form of supplementary aid or service utilized to facilitate a child's education in a regular educational environment.
4. Assistive technology may be used outside the school program if such use is written into the IEP.
5. School district are generally responsible for the provision of all assistive technology that the IEP determines is necessary for a child to receive a FAPE.

IEP LEGAL ISSUES

Recent legislation and administrative mandates have significantly impacted the access, societal acceptance, and use of assistive technology in teaching students with disabilities. New laws, acts, and administrative opinions have not only created an atmosphere promoting the use of assistive technology in education but actually mandate its application. Assistive technology is expanding the spectrum of least restrictive environments (LRE), providing additional means for local education agencies (LEA) to provide a better free appropriate public education

(FAPE) for students with disabilities, and should be an integral part of the individualized education program (IEP) process. Bergman (1987) states that "it is the responsibility of educators to see that advanced technology is used to maximize student potential and allow the [handicapped] student full access to society."

The application of assistive technology for students with disabilities is an emerging topic. At a recent Due Process Hearing Officer training attend by the author, Art Cernosia, Esq., predicted assistive technology to be one of two major areas for litigation in special education in the near future. This seminar will prepare teachers and parents to appropriately apply technology in the IEP process and hopefully avoid litigation and thwart Mr. Cernosia's prediction.

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STUDENTS WHO USE ASSISTIVE TECHNOLOGY: SCIENCE GETS AHEAD OF THE LAW

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ABSTRACT

Students who use assistive technology to sustain life raise complex clinical/legal issues in addition to traditional educational/legal ones. The legal rights of all students with disabilities in the educational setting—including those dependent on assistive technology to sustain life—have been reviewed in numerous other forums. In the following article, the author discusses "do not resuscitate" (DNR) orders in educational settings—a clinical/legal issue which in the past was confined to the hospital setting but is now also raised in the schools. Educational practitioners are facing, with increasing frequency, situations for which they have received little or no professional training or for which there have been vague guidelines. DNR orders are governed primarily by state health-related laws and the author will supplement the discussion below with relevant Washington State law.

BACKGROUND

An observant visitor to any public school classroom in this country will be struck by the diversity of the student body. Not only do most public schools reflect the racial, cultural, and socio-economic heterogeneity of the larger society, they also include increasing numbers of students with disabilities. After two decades of federally mandated nondiscrimination towards students with disabilities, state and local education agencies are becoming accustomed to serving students with disabilities in public education settings. However, just as the characteristics of the overall student body are changing, the population of students with disabilities looks different than it did twenty or even five years ago. Remarkable medical advances, combined with impressive engineering technology, have introduced new opportunities for students with disabilities to participate in community activities. These medical and technological changes, in conjunction with the legal mandates to provide educational services to children with disabilities, have resulted in increasing numbers of children in public schools who require assistive technology to sustain life.

In the past, these children simply were not in the regular education setting, riding public transportation, or interacting with others outside the institutional setting. Educators were not approached by parents or guardians requesting that they honor a student's DNR order. The world has changed. As a result of the changing school population, educators may be asked to honor a DNR order.

This issue has received minimal judicial or administrative attention, but has become a topic of intense interest and concern among school staff throughout the country. Science has not waited for public policy to "catch-up" with the rapid technological changes. The public is increasingly being challenged by difficult questions concerning the right to live or die—and who decides. There is clearly no public consensus on any of the variations of the right to life issue--as exemplified by the on-going abortion discussion. The ethical and religious dimensions of the questions will undoubtedly continue to be debated for years. But meanwhile, the law governing who and how students with DNR orders should be served has not kept pace. As science has gotten ahead of the law, educators are left without clear expectations of their roles and responsibilities.

DISCUSSION

The well established rule under negligence law is that educational staff are responsible for ensuring the safety of students in the public school setting (1). Teachers and other staff have an affirmative duty to aid injured or ill students and act in a reasonable and prudent manner to obtain immediate care for those who need additional assistance—i.e., call parents or emergency medical personnel (911) and/or provide transport to a medical facility. The case law is replete with examples of teachers and school districts found liable for the injuries to a student due to acts or failures to act.

Although there are no cases specifically on point, one can make the argument that teachers and staff working with students who use assistive technology may be held to a higher standard of care then would be expected of teachers of other students. Teachers of children who use assistive technology to sustain life are clearly on notice that such students may have equipment malfunctions or emergency medical needs. Therefore, the "reasonable" person standard in negligence law would suggest that the teacher of students who use life sustaining technology must be prepared for foreseeable problems related to that technology. Regardless of the health status of the students, the general rule is simple—i.e., *all* medical emergencies occurring at school require the full response of staff.

Applying this general rule becomes difficult when the parents of a child have a "do not resuscitate" (DNR) order—or some variation of an advance directive to a physician to withhold or withdraw life sustaining treatment — and ask that the school staff honor that request if their child needs emergency intervention in school. A school board in Lewiston, Maine has recently grappled with this issue when the mother of a 12 year-old student with severe disabilities asked that her daughter not be resuscitated if her heart stopped and presented the school staff with a DNR order (2). Originally the school board had voted 6-2 to ignore the mother's request. However, based on the testimony of the girl's physician, had reversed itself 6-3. Following intense protests from teachers and others, the board reexamined their decision again. After a hearing that lasted until 3 a.m., and included "a procession of speakers" offering legal and ethical advice, the Lewiston school board reaffirmed its decision to honor the DNR order. This decision initiated a complaint to federal officials and resulted in another reversal. Under the new policy effective February 1, 1994, teachers are no longer *required* to follow the DNR order and must develop an "individually" designed resuscitation plan to be followed in the case of emergency (3).

Many teachers of special needs children have close relationships with the whole family and may want to be supportive of the parents' request. Other teachers may have ethical or religious conflicts with DNR orders in general or for a particular child. In addition to the difficult personal dilemmas resulting from such a request, there are legal ramifications in accepting responsibility to honor a DNR order. Each state has granted authority to particular professions to honor DNR orders. School staff in most states do not legally have the authority to comply with treatment limiting directives and could face serious liability if they do not respond appropriately to a child's emergency needs.

Response of Emergency Medical Personnel: Washington State Law

Under Washington State law, a physician, health care provider acting under the direction of a physician, or health facility (4) can honor a written directive from an adult or "an authorized representative who validly holds the person's durable power of attorney for health care" (5). The directive can instruct the individual's physician to "withhold or withdraw life-sustaining treatment in the event of a terminal condition or permanent unconscious condition" (6). The first limitation to note in this statute—commonly known is the "Natural Death Act"—is that although an individual can make a directive at any time, a physician is authorized to act upon it only when one or both of the conditions exist—i.e., terminal illness or a permanent unconscious condition.

The second important limitation is that this statute does not cover emergency medical personnel who respond to an emergency in the community. However, another section of Washington law does address the situation by stating that the "department of health shall adopt guidelines and protocols for how emergency medical personnel shall respond when summoned to the site of an injury or illness for the treatment of a person who has signed a written directive or durable power of attorney requesting that he or she not receive futile emergency medical treatment" (7).

There were no written guidelines or protocols until recently. Emergency medical personnel were directed by the Washington State Department of Health to provide full response to everyone regardless of the existence of an advance directive. The individual would then be transported to a medical facility where the request could be evaluated.

Interim written guidelines from the Department of Health became effective November 1, 1993. These guidelines were developed by a working committee of approximately 25 people representing the interests of the religious community, emergency medical personnel, physicians, and the aging population. Under the guidelines, emergency medical personnel are authorized to honor a request for no assistance, if supported by either a bracelet obtained from the Department of Health or a specific Department of Health form. Any other written or verbal directive will not be recognized by emergency personnel—in other words they must continue to provide full assistance. The Department of Health will issue either the bracelet or form to individuals with written advance directives that fulfill the statutory obligations of the Natural Death

Act as described above—i.e., those who are terminally ill or in a permanent unconscious state. Those with living wills or other written requests will not receive the department bracelet or form. These limitations of coverage to only these two conditions, have resulted in efforts to expand the protocols to cover individuals with Alzheimer's Disease and AIDS—which explains why they are called interim guidelines.

Children are not covered under these interim guidelines. Therefore, in Washington State, emergency medical personnel responding to a student in school must provide all assistance and transport the child to a medical facility. Emergency medical personnel are not currently authorized to respond affirmatively to any advance directive concerning a child. According to the Department of Health, children are not being considered for coverage in the final guidelines.

Policy Considerations

The decision to obtain a DNR order for a child is undoubtedly a difficult one for most families. Compounding the moral and ethical dilemma is the fact that the law has not kept up with changing realities in the community. Some educators and parents, among others, may feel that because children with DNR orders are now in public schools, the advance directive should "follow" them. However, in most states, educators do not have the legal authorization to respond to a DNR order. And, in many states, emergency personnel do not have legislative authority either.

Sufficient numbers of educators and/or parents may believe that the laws governing DNR orders in educational settings are archaic and infringe on the rights of children and/or parents, and advocate for change. However, even assuming that there is some consensus that DNR orders should follow children into the community, how do we safeguard the rights of all involved and who should be allowed to honor the codes? One option would be for the applicable state legislature to "change the law" and introduce a bill that grants authority to educators and emergency personnel to honor DNR orders with whatever restrictions or caveats are deemed appropriate. Another option is to clearly give the responsibility to the 911 personnel, but continue to preclude educators from following the DNR order. A third option, and one adopted in Washington, is to preclude both emergency personnel and educators from following DNR orders for children in a school setting.

As stated earlier, school districts and educators confront unique clinical/legal issues when serving students who use assistive technology to sustain life. As DNR orders become more common, school districts will be faced with the necessity of deciding how they will deal with parental requests to honor them. Should educators honor DNR orders? School staff—unlike medical practitioners—have not generally been prepared for dealing with and accepting responsibility to make choices such as this when it involves their students. Fortunately, there have been no court cases specifically addressing school district or individual educator liability in this area. However, the author believes this situation will change as the number of students who use assistive technology increases unless there is open constructive debate regarding the issue. The debate will undoubtedly be difficult for all involved—regardless of one's personal perspective. However, DNR orders in the schools will not go away and the issue is too important to ignore.

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VOICING DYSLEXIA REMEDIATION

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ABSTRACT

This paper describes an adult consumer's impressions for remediating certain dyslexic traits using computer voice input and output methods. It presents a background to justify using an assistive technology approach over other strategies.

BACKGROUND

For this author, sensory integration issues, visual disabilities, dyslexia and "learning disabilities" have limited competitive performance in school and in the work place. A collection of subtle, but significant, central nervous system traits combine to form a person with a pattern of mixed capabilities--gifted in some areas and clinically deficient in others.

West has published a highly informative work describing the issues for people with a pattern of mixed capabilities.[1] Gardener's work also gives insight into the benefits, problems, and issues of different forms of native intelligences that are traditionally unrecognized.[2]

For this author, the pattern of mixed capabilities was unmasked in mid-life. Functionally, the clinical deficiencies were partially self-remediated. There has been a very high personal cost.

Three remediation options seemed plausible: retraining, personal assistance, and technology.

1. Retraining can remediate certain traits, but it is a long term, time and cost intensive process. For example: in a proper psychoacoustic environment, lack of phonetic awareness, and in turn spelling problems, could be overcome. Time commitments, social and professional obligations, and other pressures of apparent adulthood, make a commitment to such training an enormous burden. Retraining also poses certain social and financial risks. One is the high potential of a mismatch of learning style and teaching methods. Another is the hard reality that some neurological traits just cannot be fixed. For example, in this case typing and keyboarding have been a part of everyday life for thirty years. Yet, many times a simple word like "time" must be entered with conscious deliberateness, slowly and methodically, letter by letter, spelling it out loud, to avoid it coming out "teim."

2. Personal assistance is wrought with pitfalls. First and foremost, are the dependencies issues. Self-reliance cannot be fully developed. Ongoing cost is a major concern. Reliable staffing is always a problem. Outside services frequently are limited and costly.

3. Assistive technology has many pluses in this situation. By using this approach, many of the specific issues might be clustered. Despite perceptual problems, high level computer skills have already been achieved. Extensive computer experience, and an intense interest in technology are strong motivators and bring personal satisfaction.

Technology appears to be the most cost effective investment of time, resources and finances to remediate noncompetitive neurological traits and disabilities in this midlife adult--in the shortest time.

THE PROBLEM

One of the first functional clusters to be addressed by assistive technology is written communication. Both skills and rate need vast improvements. To address both issues, this evaluation tests direct computer voice transcription for word processing input and voice output as an editing assist.

Specific clinical traits are: dysgraphia, dyslexia, total blindness in the left eye, lack of smooth pursuit in the right eye, and sensory integration problems. Most common dyslexic features include letter reversals, dropping of word endings, word omissions, spelling problems, and phoneme/grapheme awareness. Structural writing errors are plentiful. Clinical testing has revealed extremely high aptitudes in creativity and vocabulary. Sensory integration issues are exacerbated by physical and emotional stress. Beyond the clinical framework, there are the personality issues of complex frustration, negative self-imaging, and resentments from previous difficult teaching/learning experiences. Dependency on outside help for assistance erodes self-confidence and self-esteem, and raises frustration levels.

IMPLICATIONS

Our increasingly literate culture demands sophisticated writing and reading abilities. In this situation, assistive technology has the potential to fully utilize the gifts, and make the neurological traits--that steal commensurate performance--transparent. It could provide competitive formal correspondence skills, save time and frustration, and improve self-confidence and self-esteem. Being able to communicate efficiently in writing will enhance business communications abilities, and widen social and professional avenues.

APPROACH

For the voice input portion of the test, a supplier furnished, IBM compatible computer with an Intel 386 processor operating with a twenty megahertz clock was used. This machine was equipped with a noise canceling, head-set microphone, voice processing board, and appropriate software.

A first draft of a manuscript was dictated into a word-processing file. These files were then grammar and spell checked.

For the voice output portion of the test, the document file was taken to another location. There, it was read back by another specialty computer equipped for high quality voice output.

For final editing, auditory, visual, and tactile senses were combined. During the voice output reading, head-phones were used to increase the signal to noise ratio. The text was followed word for word using a ball point pen to mark errors and enhance concentration.

DISCUSSIONS

When the user speaks into a microphone, the hardware and software decode spoken utterances into keystrokes for a word processor. It does not have the capabilities to decode continuous streams of speech. It must have discrete units of sound to decode. This requires the user to make distinct pauses between each word.

A criterion for competitiveness is that the voice input rate equal or exceed the evaluator's maximum speeds for handwriting or keyboarding. Maximum handwriting speed (for very simple writing) is fifteen words per minute, but the writing is barely legible and replete with faults. Key-boarding is so full of errors that any output rate is meaningless.

Good writing is an arduous process for anyone. It is difficult to separate the arduousness latent in the task with the arduousness of the perceptual difficulties--an ongoing issue in all areas of daily living. To set a reference standard for comparison, this study set a reference point of three hundred to four hundred accurate, legible, well organized, grammatically correct words per hour for simple, non-complex writing. This translates to three to six words per minute of final output.

Maximum capability was tested by speaking a traditional typing test sentence twenty times. The test sentence was "Now is the time for all good men to come to the aid of their country." This method allowed the system to build highly accurate models of voice patterns. The system achieved an accuracy rate of 97% correct at twenty-five words per minute.

The practical output rate was checked by dictating the first draft of this document. Direct transcription of these paragraphs averaged about ten words per minute. The slowness comes from having to retrain thought and speech patterns to an entirely different process of communication, not hardware or software. As with all learning, it can be expected that, even with complicated composition efforts efficiency will improve with experience. A detailed quantitative comparison with the reference standard was not accomplished.

Composition issues aside, a system limit for the speed of voice conversion prohibited any increase in input rate beyond twenty-five words per minute.

Two factors prohibit this. First, the test machine was a 386/ 20MHZ. With this clock speed, the delay time for verification slowed the process to unacceptable levels. Second, the structural nature of the utterance changes with speed of speaking. When the rate of the spoken utterance stream was increased beyond twenty-five words per minute, a much higher error rate occurred. With a faster clock and a retraining of the voice models, conversion rate could keep up.

Using the keyboard to intermittently supplement voice input increased productivity dramatically. In most cases, a recognition error on a leading phoneme was quickly corrected with just one or two keystrokes. Errors in recognition occurred if a suffix was slurred, or if the voice dropped at the end of a word. Then it is necessary to fully type out the word.

Another factor which affects the conversion accuracy is the level and type of ambient noise. The system is most accurate when it is trained and used with a constant level of background noise. The microphone supplied with the system is a head-set mounted, noise-canceling type. Even though this microphone is designed to minimize the effects of ambient noise, it is still receptive to background and impulse noises. For example, the noise of the computer fan is a constant, and does not interfere with voice modeling. However, the ringing of a telephone will be picked up, and confuse recognition of the utterance, causing an error. This, of course limits productivity. For maximum conversion accuracy and speed, a pin-drop quiet ambience is best.

Spelling errors were minimal. Only homonyms needed to be changed. Grammar checking revealed a plethora of opportunities for improvements in syntax, grammar, and structure.

Listening to the reading by the synthetic voice revealed an additional four per cent of errors, beyond spell checking.

Conclusions--Despite the limitations, the high and low extremes for productivity in this test give a first approximation of the capabilities of this method. When the software has high accuracey voice models, the output speed approaches the fastest, barely legible, error laden, handwriting. Key-boarding accuracy is dramatically improved. Greater accuracy, legibility, and actual yield dramatically increase net output. Spelling errors, inversions, and other dyslexic traits are absent.

Multisensory editing, using voice output, provides a final leveling factor for competitiveness with people that do not have cognition or sensory issues.

This test technique gave the writer his highest confidence level ever in his written work. For the first time, now there is a way to be competitive in this critical realm of daily functioning. Now, with this technology, it is not as necessary to spend as much of life's energy fighting neurological predispositions and struggling to maintain personal identity.

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Speech Evaluation of Habilitation Training of Hearing-Impaired Children in Shanghai, China

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Abstract A method of speech evaluation of habilitation training for hearing-impaired children is described. In this study, nine aspects of speech and audition abilities were evaluated. The results of following-up in 88 evaluated children indicated that this method was practical, and it was a good way to promote the hearing-speech training task for hearing-impaired children in Shanghai, China. Several factors which might affect the results of evaluation need to be carefully dealt with.

Introduction

Since 1988, with more attention paid by the authorities, the work of hearing and speech habilitation for hearing-impaired children has developed rapidly in China. So far, we have achieved initial success: about 10~12% profoundly hearing-impaired children, after training at a hearing-impaired training course, can enter regular primary schools to integrate with normal children. Our experience indicates the importance of speech evaluation throughout the training course. Evaluation following training is essential to determine whether a child has attained the skills taught during the course.[1] In this study we conducted speech evaluation for hearing-impaired children following training in Shanghai.

In order to facilitate and control the quality of evaluation, Shanghai (Re)Habilitation Office has been organizing speech evaluation annually since 1990. The candidates were selected by teachers at training centers or classes. The examination board consists of the experts including otologists, audiologists and speech therapists.

Method

An experienced teacher was appointed as the examiner. The hearing-impaired children attended the evaluation individually. The board members observed and scored during the procedure of evaluation.

Nine aspects of evaluation were conducted to assess a child's abilities of speech and audition.

1. Chinese phonetic alphabet

Chinese phonetic alphabet contains 6 vowels, 28 diphthongs, and 23 consonants. One Chinese character is composed of one vowel, with or without consonant, such as *è* (hungry), *hua* (flower). It is very important to learn Chinese phonetic alphabet for a hearing-impaired child in learning pronunciation. During evaluation, the teacher shows an alphabet, the child pronounces it. Twenty-five alphabets were used for each child with the total mark of 10 points. Therefore, each alphabet contains 0.4 points.

2. Words

(1) comprehension ability: Twenty toys and pictures, which were well known to the children, were put on a table. The teacher pronounced the name of an objects, e.g. telephone, then the child was encouraged to pick it out. Altogether 10 words were pronounced and the maximum score was 10 points, i.e. one point for one word.
(2) cognitive ability: The teacher showed an object to the child, such as a candle, then encouraged the child to tell its name, to see if the child could use correct words to express what he or she knows. Altogether 10 objects were used for each child with the total marks of 10 points, i.e. each object contains one point.

3. Short sentences

(1) comprehension: The teacher pronounced a short sentence, e.g. *Qing ni na fei zao xi shou.* (Please wash your hands with soap.) The child should imitate the action of washing hands with soap. Ten sentences were pronounced, one and a half points for each sentence, i.e. the maximum score was fifteen points.
(2) expression: The teacher showed a picture and asked the child to tell the meaning of it, for example *Ba ba zai kan shu.* (Dad is reading a book.) Ten pictures were showed, with one and a half points for one picture.

4. Questions

The teacher asked a question, then the child answered it. For example: *Ni jia zhu zai na er?* (Where do you live?) Twenty questions were asked, with two points for each question. The maximum mark was forty points.

5. Repeating sentences

The teacher read a long sentence, the child repeated it immediately, e.g. *Xiao nü hai ba shou pa liang zai sheng zi shang.* (The little girl is hanging out a handkerchief on the string.) or *Zhuo zi shang you mian bao, niu nai he guo jiang.* (There are bread, milk and jam on the table.) Fifteen points for 10 sentences, i.e. one and a half points for each sentence.

6. Telling a story according to pictures

Four pictures were placed in order according to their context. The child was asked to tell a short story. Ten points for four pictures.

7. Discrimination of four tones

In Chinese language different characters may have the same alphabets, such as *da* and *dà*. The meaning and character for *da and dà* are quite different: *da* means strike or hit, while *dà* means big or great. So, it's necessary for a hearing-impaired child to practise the four tones. During evaluation, four cards were placed in front of the child. The alphabet on each card was the same, but the four cards presented different tones. e.g. *da, dá, da, dà*. The teacher pronounced the alphabet with one of the four tones, the child should point out the card which contained the tone pronounced by the teacher.

8. Discrimination of environmental sounds

Ten environmental sounds, including thunderstorm, dog barking, cock crowing, baby crying, cough, drum, train, ambulance, bicycle, fire cracker were produced by a

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tape recorder consecutively. The child should tell what sort of sound it was. Half a point for one sound.

9. Speech perception in noisy background

Fifteen objects and fifteen pictures were placed in front of the child. A word such as "banana" or a short sentence such as "The little girl is watching TV" was produced from the tape recorder with background noise. The child should be able to point out the banana or the correct picture. Five points for 10 words, and another ten points for ten sentences.

The full mark for the nine aspects above was 150 points.

Grading

With the reference to the "Five Grades Standards of Aural Habilitation" of Chinese Association of the Disabled[2], the mark between 141 and 150 points is equivalent to Grade I, mark 121~140 Grade II, 91~120 Grade III, Marks below 90 is regarded as fail, which is equivalent to Grade IV or V.

Results of Evaluation

Since 1990, we have conducted speech evaluation for 88 hearing-impaired children, among which 17 children achieved Grade I, 15 Grade II, 17 Grade III, and other 39 Grade IV or V. Those with Grade I and II were enrolled into regular kindergartens or normal primary schools. Among the 17 with Grade III, 14 have entered regular school while the rest, together with those with Grade IV or V, have been sent into deaf schools.

Following-Up

Following-up was conducted to the children who passed the evaluation (Grade I to III) and entered a regular school thereafter. Their progress, including scores, behavior and communications abilities were recorded. It was found that the students achieved Grade I habilitation were able to study and take part in various activities actively; and most obtained good or excellent marks. The students with Grade II habilitation were able to catch up with their normal peers and/or achieve good marks. Of the 17 students with Grade III, 13 were able to catch up with the normal hearing peers, but they need extra tuition from their parents; one student was left behind, and other three entered directly into deaf schools. Some cases are as follows:

1. Ni Zhu had average hearing loss of 80dB SPL(L) / 70dB SPL(R). After training course of 18 months, she achieved Grade II habilitation, and entered a regular primary school. She has achieved good scores and was awarded a "Model of self-reliance" last September. She is now studying at the 4th grade of the primary school.

2. Lu YE had average hearing loss of 80dB SPL(L) / 85dB SPL(R). Her score was below 90 during the evaluation in 1992 and had further speech training for one more year. She achieved Grade II during the second trial of evaluation. In September, 1993, she entered a regular school and has been able to integrate herself with normal hearing children.

3. Tao TONG had average hearing loss of 100db SPL binaural. Following four-year training, he obtained a Grade III habilitation and entered a regular primary school. However, he was not able to catch up with his peers and left the school four months after the entrance.

4. Peng CHANG had average hearing loss of 90db SPL binaural. Following the training of three years, she took part in the evaluation and reached Grade III habilitation. Since that time, she has been studying in a primary school for two years. She could follow the teaching with effort, and her father had to tutor her almost every evening.

Discussion

The results of following-up suggest that the speech evaluation method used in this study be practical. It demonstrates the general level of speech and audition habilitation of hearing-impaired children. Grade I means that with the help of hearing-aids, the ability of a hearing-impaired child in speech and audition may approach that of a normal hearing child, with the indication of integration with little difficulties. Grade II means that these children would be able to integrate with other students, with limited difficulties in the class of regular schools. Among those of Grade III, some can study in a regular school with more or less difficulties, while the rest need further training. Grade IV and V mean the ability of communications of the hearing-impaired children is poor, further improvement is necessary in their training center, or they might be sent to deaf schools, according to their age.

The annual evaluation, within whole city range, is a spur to teachers, clinicians, and parents. It can raise the initiation in the training tasks. Teachers are always trying to have more children they taught to pass the evaluation. Parents always eagerly look forward to having their child to reach a fairly high level of habilitation. To our experience, this is a good way to promote our work for deaf children. The same method of evaluation were adopted by some hearing and speech habilitation centers in order to determine, at the end of each semester, whether the hearing-impaired children learned the skills which had been set out for the semester. On the other hand, the hearing-impaired children can get more chance to be familiar with the method of evaluation.

There were some factors that might affect the results of evaluation in this study, such as: some of the hearing-impaired children might be nervous slightly when attending the evaluation because many people were watching aside; the scoring was sometimes not precise during evaluation, e.g. in "Repeating sentences", if the child made a few mistakes, the score he or she get might not be exactly the same from each board member.

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INNOVATIVE INTERAGENCY COLLABORATION: PROMOTING THE INCLUSION OF A STUDENT USING AUGMENTATIVE COMMUNICATION IN REGULAR EDUCATION

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Abstract

Children with disabilities in Maryland can now access assistive technology services through different public and private agencies. These include assistive technology teams affiliated with several public school systems, private health care providers, the Maryland Technology Assistance Program (MD TAP), and the Center for Technology in Education (CTE). When barriers to independence remain despite the availability of assistive technology services, there is a need to cultivate crucial connections among the players (individual consumers and agencies) involved in serving children with special needs. This case illustrates a powerful model for interagency collaboration to support the inclusion of a student using augmentative communication in a regular classroom. The outcomes gained through collaboration produced an action plan which included immediate steps toward an equipment loan, staff training, developing strategies for integration into the classroom, and a method for measuring progress.

Background

This case study centers around Andrew, a seven year old student with autistic tendencies. Andrew's parents have invested a lot of time and effort to understand his condition and explore strategies that may help him succeed. When asked about their experiences as they sought additional professional input and suggestions, Mom laughed and made some observations. "Professionals assume you *[parents]* don't understand your child and your child's condition. They're trained with the skills and protocol to evaluate students but have a tendency to move parents away from the process." When Andrew moved into a regular first grade classroom, Mom and the school system requested assistance in determining an effective communication system for Andrew to use in and out of school. That differed from previous assessments in that the assumption was that Andrew could use a communication system. The objective was to find an effective system, not determine whether or not he could use one.

The composition of the team which met included both of his parents, representatives from his local education agency (his instructional aide, speech language pathologist, case manager, and the director of special education), an assistive technology specialist from Maryland TAP, and three members from the CTE's STAT team (an augmentative communication specialist, an occupational therapist, and a physical therapist). Each member of this collaborative team brought unique assets to the table. Mom and Dad brought a vision for Andrew as well as an unmatched knowledge of him as an individual. During his entire school career, they will be the one constant team member. The LEA knew what educational goals Andrew needed to meet and what resources, human and financial, they could utilize to meet Andrew's educational needs. CTE brought a breadth and depth of experience unavailable locally. MD TAP provided short term equipment loan and ongoing training and technical assistance to support the LEA and family.

The STAT team evolved from a federally funded project designed to train the trainers in assistive technology throughout Maryland (Fields, 1991). This project developed a unique model for training school based professionals through assessments of individual students. Training occurs during the visit as school professionals gain hands-on experience with specific technologies and assessment strategies. The local school team then takes primary responsibility for following up on next steps identified during the assessment.

Objectives

As consumers and professionals search for ways to assure provision of competent assistive technology services, it is essential to build collaboration among service providers. Collaboration relies on a team approach in which there is respect for each members' expertise and willingness to share the responsibility for problem solving and generating potential solutions. The objective was to build a team comprising key players strategically selected for their ability to facilitate change. In this way it was possible to generate solutions which exceeded the contributions made by individual expert consultants.

Approach

The STAT team relies on a collaborative consultation process to facilitate mutual problem solving among all the participants: consumers, parents, advocates, and local school professionals (Locke & Mirenda, 1992). After giving background information about the STAT Team during the introductions, there is overt acknowledgment of the expertise contributed by parents and local school professionals who work with the child on a daily basis. There is also an established sequence of events outlined for building the process of developing creative solutions. This includes:

(1) reviewing the reasons for referral,
(2) distinguishing specific technology strategies to explore,
(3) conducting actual technology trials with the child in arena style evaluation format (Locke & Mirenda, 1992),
(4) discussing observations about the child's responses as well as elaborating on strategies that seemed to work, and
(5) developing an action plan that targets the next steps to take toward implementation of specific assistive technology strategies.

Examples of action steps include but are not limited to: technology loans for trial use, exploration of different strategies, fabrication of light technology, searching for funding resources, requesting additional services from other consultants, coordination of staff training, and plans for measuring progress with implementation. The local school team takes the primary responsibility for implementing the action plan which they develop.

Results

The assessment process revealed that Andrew used a variety of augmentative communication strategies:

(1) imitating sign language modeled during group discussions in class,
(2) independent use of microcomputers for practicing math skills at school and for educational and recreational activities at home,
(3) pointing to or physically manipulating objects or people,
(4) informal eye gaze,
(5) trial use of voice output communication aid with an alphanumeric keyboard for three weeks, and
(6) trial use of a communication board with letters, numbers, "yes", and "no" choices.

Both parents and school staff agreed that Andrew showed a preference for using devices with speech output and microcomputers controlled via mouse or standard keyboard. Parents wanted to consider Andrew's need for use of facilitated communication techniques to increase his participation in academic subjects. All participants expressed interest in finding strategies to promote Andrew's ability to initiate more independent communication in social interactions at school and at home.

The trial phase of the assessment found Andrew achieved the most interaction using a voice output communication aid (VOCA) in the context of a familiar art activity. When use of the VOCA was modeled, Andrew demonstrated the ability to imitate key pressing. As he became engaged in the activity, Andrew began to initiate requests for art materials using the picture symbol overlay on the portable VOCA. He also started to construct messages by combining two symbols in sequence. His speech language pathologist commented that trial of a similar activity using only a picture communication board proved less successful.

When the team discussed observations about the technology trials, there was interest in exploring how to integrate a VOCA to enable Andrew to initiate communication in everyday activities. The question about Andrew's need for physical assistance to promote communication posed a challenge to address. By keeping focused on Andrew's needs, the team reached a consensus (Grady, Kovach, Lange, & Shannon, 1993). It was evident that Andrew requires more intensive assistance when he participates in particularly challenging academic activities. This enabled school staff and his parents to realize there is no one communication strategy that is effective in every situation.

By conducting a careful analysis of Andrew's participation level in daily activities, the school team could determine when and how to incorporate the variety of communicative strategies Andrew needs to use: sign language, speech output from a communication device, and physical assistance to facilitate communication by spelling.

Through this collaborative process, several notable results were achieved. Communication strategies were developed as a team that could be implemented immediately through the short term loan of a VOCA through Maryland TAP. After identifying individuals (the instructional aide, speech language pathologist, case manager, and parents) for whom it was appropriate, training and technical assistance in programming and using the VOCA were made available. The director of special education agreed to authorize administrative leave and substitutes to allow a specified time for planning and training. The school team also designated a date to review progress toward action steps identified during this process. If the school team found the VOCA an effective communication strategy for Andrew, the case manager agreed to pursue funding options. In addition, if there was a need for staff to receive training in facilitated communication techniques, administrative support was available.

Ratings from feedback forms given immediately after the assessment found that participants valued the exchange of ideas during the assessment. All participants rated the experience as beneficial for Andrew. When asked to compare this collaborative model to past experiences, Mom responded that "We were actually invited in like everyone else, we were part of the team. This process gave my husband and I credibility." In the longer term, this collaboration set the environment for what the Director of Special Education, described as "...more ongoing cooperative planning between the school based team and Andrew's parents.".

Discussion

Andrew's case illustrates how a collaborative approach to problem solving can facilitate outcomes with extensive impact. Each member of the school team accepted responsibilities related to their role in meeting Andrew's educational needs. Including the director of special education in this process created an environment which allowed staff to develop solutions with administrative support for implementation.

The success of this collaborative team effort rests, in part, on it's assumptions about who is important to include on the team. Virtually anyone who knows the student and/or who can impact the selection, acquisition, training with and maintenance of assistive technology could be included in a collaborative team evaluation. This includes teachers, therapists, family (parents and siblings), peers, sitters, technology specialists, funding representatives, voc. rehab., etc. A fluid team looks at the needs of the students and then assembles a team to address those specific needs.

The factors most critical to the success of a collaborative team model evaluation include:

• **Thorough background information**
This is imperative to have any degree of effectiveness during the team assessment. This collaborative team may not have the privilege of first hand knowledge of the student so it must depend on the background information provided by the local team.

• **Clear goals and objectives**
A 'general technology' assessment is a ticket to disaster, or at least frustration. The visit will only last a short time, so having very clear goals will make a quantum contribution to the chances of success.

• **Respect for the local team**
They're the best source of information about what might work, or at least clues to what will be effective strategies and will be the team that will make or break the assessment. Trust them and work WITH them.

• **Brainstorming strategies**
Not only will this yield creative strategies, but the process of collaborative brainstorming invests all participants in implementing the action plan.

It is critical that a more collaborative model be adopted at this time because there is an ever-increasing need for assistive technology to assist with the integration and education of students with disabilities. The onus of implementing those technology solutions needs to be on local and regional teams that can be replicated rather than on a few individual experts.

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SIG-07
Technology Transfer

APPLYING ASSISTIVE TECHNOLOGY CONCEPTS TO NON-DISABILITY PROBLEMS

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ABSTRACT

Evaluation of the instrumentation layout in a large commercial airplane revealed aspects that handicapped pilots and contributed to decreased flight efficiency. A potential remedy has been derived from disability-focused research. The experience indicates that there may be many opportunities to transfer assistive technology concepts to non-disability applications.

BACKGROUND

What do a quadriplegic and a Boeing 747 pilot have in common? Answer: They are both handicapped by aspects of their environment which can be ameliorated by a common solution. During a review of the cockpit instrumentation of the Boeing 747-400, researchers concluded that features of the layout reduced the efficiency and effectiveness of pilots. Specifically, it was concluded that the pilots are "handicapped" by the location and layout of the keyboard in its Multipurpose Control Display Units (MCDU), which provide access to the plane's computer systems. Because of cockpit design restrictions, the MCDUs are located in the center console where they can be accessed with only one hand by the pilot and co-pilot. Moreover, either the right or left hand must be used to key in data depending on whether the user is seated at the right or left of the console. The configuration is such that the users' only recourse is to enter data with a single finger.

PROBLEM

The slowness of single finger data entry discourages computer usage, and therefore, results in sub-optimal reliance on the plane's computer-based Flight Management System. Because computer managed flight is more efficient and reduces flight time and fuel consumption, failure to use the system contributes to higher operating costs. Additionally, when data is being entered, the user's attention is drawn away from other functions. Thus, detraction that occurs during data entry is a safety concern.

APPROACH

When the researchers recognized that the pilots were handicapped by the arrangement, they initiated a project directed at improving the situation. Relocation and complete redesign of the computer data input system were determined to be unfeasible because of cost, safety, regulatory, and other factors. Consequently, researchers were driven to exploration of other means by which to increase data entry rate and ease of computer use. When researchers conceptualized the problem as that of a handicapping environment, they began searching disability/handicap data bases for help. Their efforts led them to the published work of Chubon and Hester (1, 2) regarding the enhancement of standard computer keyboards for single finger and typing stick typing. Subsequently, the researchers applied the concepts to the Boeing MCDU problem.

Efforts centered around increasing the rate of data entry. The Boeing researchers were able to use the idea of rearranging the keyboard layout to minimize finger travel distance, as well as measures to facilitate scanning and locating keys. The Chubon-Hester layout developed for standard computer keyboards and based on letter usage frequencies in the English language could not be utilized directly. The alphabetic keys on the MCDUs were arranged in six rows containing five keys, creating a nearly square configuration. Moreover, the data to be entered consisted of individual letters and nonsense syllables representing acronyms, abbreviations, etc. As Chubon and Hester indicated, however, custom minimal finger travel distance keyboard layouts can be derived to suit specific user requirements. The Boeing researchers conducted letter usage studies of actual pilot MCDU input and determined individual letter and bigram frequencies. The frequencies were then used as the basis for rearranging the key layout on the console, clustering the most frequently used letters together. In the Boeing layout, the letter A was placed at the center because it had the highest frequency. The resultant layout was determined to require approximately 25% less finger travel than the original alphabetically ordered key arrangement. Subsequently, the letters denoting directions, NESW, were relocated around the letter A in map positions to facilitate location and orientation. Although their relocation resulted in a slight increase in finger travel distance, it was posited that the increase would be offset by diminished scanning time.

DISCUSSION

Analyses of potential increase in data entry rate and computer use indicated that the costs of converting the keyboard layouts to the minimal finger travel distance configuration could be recovered in less than two years. However, extensive testing will be required to evaluate pilot acceptance and other human factors. As Chubon and Hester pointed out, mathematically correct keyboard models do not assure optimal human performance. Negative transfer from use of other key arrangements and other human factors often weigh heavily in determining usage and effectiveness.

IMPLICATIONS

Perhaps the most important outcome of this experience, to date, is that it has revealed the potential for applying assistive technology concepts to non-disability related problems. This was a departure from the usual flow of technology developments from non-disability to disability applications. Expansion of the market for assistive technology beyond the disability realm can contribute to increased production and lower cost, resulting in wide ranging benefit. Additionally, the experience underscores the importance of publishing disability research.

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STUDY OF ACCESSIBLE MICROWAVE OVEN DESIGN

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ABSTRACT

This paper explores accessibility of microwave ovens to people with disabilities. Two manufacturer's microwave product lines are reviewed, determining the functional accessibility to the microwave for people with different disabilities. Redesign options to improve accessibility are presented.

BACKGROUND

The question exists as to how accessible technological products are to the more than 40 million American consumers with disabilities. (1) Besides preventing the individual with a disability from enjoying modern conveniences and performing simple tasks taken for granted by the rest of society, denial of access to these products is discrimination. Ideally, commercial consumer products could be designed from the beginning so that anyone could use them, regardless of ability. In producing a product accessible out of the box, the market for that product is expanded to include people with disabilities. This is a concept known as universal design. In many cases, relatively simple design changes by an informed designer can increase accessibility and ease of use for *everyone*. While some research exists concerning universal design and application to the disability community, little focus has been placed on specific consumer products. (2) The microwave oven is chosen here as a specific and relevant consumer product to study.

OBJECTIVE

In analyzing the accessibility of the microwave oven product, it is useful break down and evaluate the different functional aspects of microwave usage. The functions can then be reviewed for accessibility relative to different disability categories. Good design features and potential areas of redesign can be identified, providing information to manufacturers to increase understanding of accessibility issues. In the process, consumers are informed of the current accessibility status of technology in general.

METHOD

Whirlpool and General Electric were chosen as representative manufacturers of microwave ovens. First, a detailed analysis of specific microwave models was performed, concentrating on functional characteristics. The major task involved in microwave usage is heating a food item. All functions directly involved with achieving the major task are categorized as essential functions. Such essential functions include:

- opening/closing of the door
- insertion/extraction of food item
- setting power level and cook time
- starting/stopping the cook cycle

Additional nonessential functions (those functions available but not necessary for completion of the major task) include:

- setting the clock
- setting a timer
- using a heating probe

In addition, the consumer help service was contacted for each company to gain additional literature and information and also to gain further insight into the sensitivity of the company to accessibility issues.

RESULTS

While the assorted models of microwaves produced differ somewhat in appearance, a "standard" version of microwave oven becomes clear after evaluation. For instance, the vast majority of available microwaves have a flat membrane keypad by which to enter commands and control functions such as power level and cook time. Primary feedback on these functions is generally given by a digital display panel while secondary feedback comes through tones sounded as buttons are pushed and when cook cycle is complete. Of the nearly 60 different models of microwaves produced by GE and Whirlpool, all but four models are configured this way. The remaining models (all compact or sub-compact) have dials or function control knobs and analog status displays. In addition, door access generally occurs by overcoming a friction latch by pulling the door handle or by pushing a button to release the latch.

DISCUSSION

The term disability covers a broad range of conditions. Generally, though, disabilities can be placed in one of four categories: physical disabilities, hearing impairments, visual impairments, and cognitive disabilities. Discussion of accessibility to the microwave is done in terms of accessibility for the different disability categories. For sake of simplicity, multiple disabilities are not addressed.

Physical Disabilities (impaired range of motion, paralysis/amputation, weakness, control difficulties, and impaired tactile discrimination):

Food Manipulation: It is important to realize that some limitations preclude the use of a microwave, regardless of the microwave itself, by preventing the completion of the essential function of insertion/extraction of a food item. For example, someone with extreme control limitations may have great difficulty placing a cup of water in the microwave without spilling. The success of such manipulations are dependent on the size, shape, and type of the food item. However, of primary concern here is the actual accessibility of the microwave rather than the food items which must be manipulated.

Door Opening: A person with weakness, limited use of arms and hands, or control difficulties may have a lot of trouble grabbing the door handle and pulling it open. ADA building guidelines specify that doors should require less than 5 lbf to open, and it is reasonable to transfer this guideline to microwaves. Most handled models of microwave require between 7 and 15 lbf to open - more than desirable. For models which require pushing a button to release the door, generally less than 4 lbs of force is required, but fine motor control is necessary to be able to activate the door release button.

Keypad Button Activation: These buttons tend to be small (~1/2" square) and therefore pose a problem for people who lack fine motor control and are unable to accurately select a button without inadvertent activation of neighboring buttons. Also, there is no tactile feedback given to indicate that a button is pushed, possibly contributing to selection difficulty.

Temperature Probe Use: Microwave models which have this feature utilizes a 1/4" phone jack/plug as a connector. The placement of the jack inside the microwave is critical in determining the awkwardness of the motion of plugging in the probe, especially for an individual in a wheelchair. One GE model placed the jack on the rear part of the side wall, almost a foot from the front of the microwave. It would be awkward to try to reach all the way into the microwave and try to guide a plug into the jack. A Whirlpool model more appropriately placed the jack as close to the front of the microwave as possible.

Hearing Impairments (hearing deficits and total hearing loss): The facet of microwave function which most effects an individual with a hearing impairment is audio feedback. For most models of microwaves, a tone is given when each selection button is pressed. Inability to hear this would interfere slightly with ability to enter cook time and power - essential functions. Also, all microwaves give some sort of audio signal when finished with a heating cycle. Usually, though, there is also visual feedback coupled with the audio feedback in the form of status readings on the digital display. Therefore, the only real concern for people with a hearing impairment is knowing when the cook cycle is finished when they are not in close proximity to the microwave, and therefore cannot see the display reading. This difficulty would not prevent the completion of the major task, and it can be concluded that microwaves are quite accessible to people with hearing impairments.

Visual Impairments (low vision and blindness): Of major concern for people with visual impairments the amount of visual information which is presented in relation to the microwave for identification and discrimination of functions and status.

Feedback: In terms of feedback, there is no tactile feedback which would indicate which button is being activated or even where the buttons are located, and so individuals with a visual impairment are forced to rely on the limited audio feedback described in the section above. Also the digital display tends to be small and hard to read, so visually impaired individuals would have a difficult time utilizing that feedback as well. One difference between manufacturers is in status indicator labels such as "power" or "cook level." All GE models include these in the digital display, and so the words are at most 1/16" tall. Whirlpool has some models in which these labels are printed on the membrane with LED arrows pointing to the appropriate words. This allows the status labels to be printed larger and be easier to read.

Labelling: The major problem with labelling is difficulty in differentiation between keypad buttons. Both companies indicate that braille overlays for the keypad are available for their microwaves, but braille is not useful for the 70% of visually impaired individuals who do not read braille. Also, the GE braille labels are stickers with a rather cryptic coding system which must be applied by a sighted person (as stated on the printed instruction sheet sent with the braille labels). The Whirlpool version is a true overlay which can be installed by someone who is blind. Whirlpool also offers the Use and Care Guide and a cookbook in braille, large print or audio tape.

Cognitive Disabilities (memory impairments,

language deficits, and difficulty with abstractions):
Button sequencing memory: The method for setting power level, setting cook time, setting the clock, and setting the timer are each very similar for each membrane keypad microwave. Each function requires a sequence of 4-5 key depressions, making the total number of depressions for the whole task at least 12 for the most complicated plan. Most models have simpler settings which would allow power and time to be selected by a single touch. A sequence of three is much simpler to remember than a sequence of twelve.
Label Abstraction: Some models have pictures or symbols which need to be interpreted in order to make use of them. For example, a picture of a popcorn kernel may set the time and power level as appropriate for microwave popcorn. For the person making popcorn, this is fine. For the person cooking vegetables, however, it may not be simple to think that vegetables = popcorn, even though the time and cook level may be completely appropriate, and so the individual may unnecessarily go through the longer sequence of button pushing. There is a high level of abstraction here which must be considered.
Literature: A complex and wordy owner's guide will make it difficult for some individuals to understand. In general, the Whirlpool manual contained simple, step-by-step instructions which were accompanied by pictures. The GE manual tended to have longer narratives and was relatively more difficult to follow.

CONCLUSION

The following is a list of design features which would make the essential functions associated with the use of a microwave oven more universally accessible. These features will not only aid people with disabilities, but also make the microwave oven easier and more convenient to use for all people.
Levered Door Latch: A push button release mechanism is recommended that has a large activation area and makes use of leverage to decrease the necessary applied force. The door should be able to be opened with a closed fist.
Large Button Models: Large buttons would not only assist those with visual impairments to see the buttons and labels more easily, it would also help those with control difficulties to accurately make a selection. Availability of a keyguard would also be appropriate.
Large Display: A large display would improve readability of the visual feedback.
Voice Output Feedback: A means for the microwave to "speak" the buttons as they are pushed and a method to "read" the display would serve to give the visually impaired audio feedback to aid in their use of the microwave. Also, for a person with a language deficit (e.g. a learning disability which hinders them from reading numbers correctly), the voice output could greatly clarify the status of the microwave and make sure that commands are entered correctly.
Single Touch Settings: Many models already have single touch settings which avoid long activation sequences and aid in the cook cycle programming.
Tactile Feedback in Buttons: Allowing the user to feel when a button has been activated will help those who cannot use the visual or audio feedback.
Readable Literature: All literature associated with the microwave should be as readable as possible for the user. First, it needs to be in a form that the user can access - braille, large print, and audio-taped versions are a very good idea. Also, the actual writing of the literature should be clear and concise, with instructions simple, warnings obvious, and utilizing pictures and diagrams as much as possible.

Both manufacturers are definitely aware of some needs of people with disabilities, but there is always room for improvement. With increased information and sensitivity concerning people with disabilities, these and other companies are on the road to providing consumer products which are more useable by everyone.

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Accessibility Evaluation of Current Television Design Trends

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ABSTRACT

The accessibility of television to people with disabilities is becoming more important as television provides greater news, information, and entertainment services. This paper reviews the current accessibility of television sets. How well current television controls and displays address the requirements of people with physical disabilities, cognitive disabilities, visual impairments/blindness, and hearing impairments/deafness are considered. Possible redesigns are discussed.

BACKGROUND

Researchers have recently attempted to formulate methods of rating product accessibility for all disability types [1,2]. Often this has entailed reduction in the number of distinctions between different types of disability in an attempt to produce a 100% accessible product design criteria [3]. While the validity of such universal design is still debated, these studies provide a good resource for determining possible product design changes.

INTRODUCTION

The Americans with Disabilities Act (ADA) and the growing involvement of people with disabilities in the consumer movement have created an atmosphere through which citizens are achieving a higher quality of life. Television is a very popular form of information and entertainment dissemination in our society today. It is therefore reasonable for people with disabilities to both desire and expect the accessibility of television should they choose to use it for entertainment, information, etc.

Currently, television sets have many features which may greatly enhance out-of-box accessibility if certain changes were made in their application. It is proposed to review current trends in television set design to determine which changes are appropriate. The television models reviewed are the Zenith™ and Quasar™ brands and other after market products such as remote controls.

DISCUSSION

Accessibility was evaluated for each of four disability groups: (1) Physical Disability; (2) Cognitive Disability; (3) Visual Impairments/Blindness; (4) Hearing Impairments/Deafness.

Physical Disabilities: Physical disability lends itself more to access difficulties due to the television set's controls.

- Action: Push buttons switches appear to be superior to other switches in this case. Prehension of pull and rotary switches can be difficult. Both television lines used push buttons on the television set and the remote control.
- Location: Placement at a height between waist and chest on the front of the set is important for people in wheelchairs or people with limited range of motion. Both brands placed push button controls centered below the screen. Placement with sufficient surface area to prevent activation of surrounding switches is significant. Zenith™ sets had 3/8" x 3/4" push buttons successively in a line. Quasar™ sets placed 1/8" round push button controls behind a flip down door. This placement made it very difficult to access the controls even for able-bodied persons.
- Activation Force: This should be small enough for individuals with low strength to actuate the switch, but a delay on reactivation would be advantageous to people with limited control. Zenith™ sets had activation forces of 225g whereas the Quasar™ sets were 100g. In comparison, lift switches usually require about 300g implying these forces are not excessive. Neither brand had a delay feature on their switches.
- Texture: Switches with dimpled or friction surfaces prevent slipping of the actuator, be it a finger, mouth stick, etc., off the switch surface. Zenith™ switches are smooth without a friction surface, whereas Quasar™ controls are roughened, but are very small. Changing to a switch with a depressed surface may help to keep one's finger, mouthsitck, etc. on the switch. Many remote controls have friction surfaces which adds to their accessibility.
- Shape: Shape seems to be less an issue if push buttons with sufficient surface area are used. With pull or rotary switches, surfaces with varying diameter and splined sides respectively are appropriate. The small size of the switches

on the Quasar™ sets left them relatively useless.

- Feedback: Regardless of switch type used there should be at least two types of feedback: a tactile and audible "click". Zenith™ sets provided both modes of feedback, whereas the Quasar™ sets provided little tactile and no audible feedback. Remote controls with this feature have increased accessibility.
- Labeling: Text, symbols, and color should be used to allow discrimination of the power switch from other switches. Switches on the set did not always display this feature. However, the remote controls had red colored power switches.

Cognitive Disabilities: Cognitive disabilities lend themselves more to difficulties with displays.

- Information Presented: The amount of information placed on the control pad of the TV or remote control and resulting screen displays can play a large role in confusing not only people with cognitive disabilities but also the general public. Zenith™ low end remote controls presented information in an uncluttered simplified fashion, but higher end models of both brands came with relatively complicated button layouts. Quasar™ screen display of functions such as volume, picture, and channel are exceptional. All functions are presented on the screen in three colors with both text and symbols. Movement between main and submenus is easy and intuitive.
- Presentation Format: Formats which rely solely on printed text for the relay of information may create a handicap which would not exist if the display included abstract or concrete symbols. Zenith™ sets used symbols in a limited fashion whereas Quasar™, through on screen displays, used symbols extensively.
- Display: Information presentation should flow either from left to right or top to bottom. Running level bars (ie, volume) should rise (top) and fall (bottom) with increases and decreases in output. Both brands used horizontal bars to display information. Also, headings should be prominent, that is highlighted or in a different color. Both brands used this feature effectively.
- Location: The placement of information should be easily seen. If on the control pad or remote control, the button or switch identifier should be obvious. Placing switch labels on the switch instead of next to them aids accessibility. Also, positioning switches in easy to reach areas reduces the possibility of an added frustration.
- Sound: If a sound occurs during manipulation of television functions, the sounds should be distinct and at a relatively high or adjustable volume. Neither brand demonstrated this feature.
- Visual: The size or height of text should allow for easy reading, color should be used to enhance discrimination between different functions. Both brands used this feature well.
- Tactile: Switches and remote controls should exhibit the use of different button shapes, sizes, and textures. The use of patterns is another technique to enhance accessibility. Neither brand used raised letters or numbers on the set or on the remote control. Buttons in the shape of their function such as an arrow directed up for higher volume or channel is more intuitive.
- Feedback: Buttons should "click" both audibly and tactually. On screen running displays (ie, volume) may also provide intuitive feedback.

Visual Impairments/Blindness: A colleague asked why I was bothering with this group of people with disabilities. Visual Impairments and blindness do not end a persons desire to keep up with the news or enjoy a drama or comedy. Television accessibility to this group is as valid as it is for the general public. Obviously, visual displays are of less concern here, however this increases the need for accessibility to other methods of interaction.

- Format of Presentation: Most people with visual impairments and blindness would have little trouble accessing a television if only the controls were arranged in an intuitive manner. The use of raised numbers or button shapes relative to their function may accomplish this goal. With continuous use of a remote visually impaired persons may become used to the layout. Some brands of remote controls use raised numbers and letters and shaped volume, channel, and VCR buttons, or have certain buttons with dimples to serve as landmarks.
- Visual: The proper sizing of screen text, or its adjustability, can determine whether a standard feature allows access. Neither of the brands allowed for screen text sizing.
- Control Action: The rotary switch is often considered to be the most intuitive switch for people in this group. However, if the controls are arranged in an intuitive manner with some type of landmark identifying the control layout, then the controls become useful and push buttons may allow access.
- Texture: Braille is based on outward dimples. Possibly dimpled overlays could be offered.
- Shape: The shape of the control is probably the most powerful design change that could be made for this group. Controls with raised shapes or buttons with shapes indicative of the control

function greatly increase accessibility.

- Labeling: Labeling need not only be in painted text, but could also be raised text.
- Feedback: Feedback in the form of sound or tactile is important since the result of control activation on the screen may not be seen clearly or at all. Possibly an add-on box could provide audible identification of channels.

Hearing Impairments/Deafness: Accessibility for people with hearing impairments and deafness has improved with the mandatory inclusion of a closed captioning chip in every television set. However, this has opened new issues such as how to best display text on the screen.

- Format of Presentation: The way in which captioning is presented should allow viewing of other on screen information. Some sets allow the user to expand the captioning from the normal three lines to the whole screen. However, when this feature was activated the picture was covered with a black background.
- Visual: The correct sizing of screen text, the rate of text presentation, and the contrast of text determine readability. It is most effective to maintain good contrast between text and background since the rate of speech cannot be controlled.
- Feedback: Tactile feedback upon control activation is important for this group.

RECOMMENDATIONS

Bringing these design changes for all disability groups together into a more accessible television can be achieved by defining four basic functions of television operation: Power On/Off, Volume Adjustment, Changing Channels, and Picture Adjustment.

Power On/Off The switch should be a push button type of sufficient surface area, low activation force and a delay on reactivation. A friction or depressed surface and tactile and audible feedback is likewise advantageous. This switch should be labeled by using raised text or symbols and the effective use of color.

Volume Adjustment Controls should be arranged vertically with either function representative shapes or raised text or symbols. Sufficient space between switches is important. Visual feedback should be supplied on the screen possibly in a vertical running bar. Closed caption should provide good contrast, while also allowing view of the screen. Possibly an auxiliary stereo headphone jack with adjustable volume could be supplied so people with hearing impairments could watch along with people with better hearing. Braille overlays may add additional accessibility.

Changing Channels Controls should be as for volume adjustment. Visual feedback on the screen and possibly voice feedback for people with visual impairments or blindness.

Picture Adjustment Simplified control layout on the remote controls can aid the comprehension of this function. Screen display with good use of color, symbols and text are important.

Of these four functions, access to power on/off, volume adjustment, and changing channels could be considered essential functions since they are commonly used. Picture adjustment is usually not reset often. Many current sets have out-of-the-box factory adjusted pictures. As such, picture adjustment is less essential as the other functions.

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SUPPORT FOR TECHNOLOGY TRANSFER IN THE ONTARIO REHABILITATION TECHNOLOGY CONSORTIUM

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ABSTRACT

This paper describes the approach that a rehabilitation research and development organisation has taken to fulfil its mandate to "address the technology needs of consumers, while building a stronger research base to effectively transfer relevant technology to the industrial sector." Four factors which are useful for the promotion of an organisation's product development culture are delineated.

BACKGROUND

In 1991, the Ontario Ministry of Health established the Ontario Rehabilitation Technology Consortium (ORTC), consisting of a collective of teams investigating the design and appropriate use of rehabilitation technology (1). Members of the Consortium are affiliated with: the Hugh MacMillan Rehabilitation Centre, Ontario Institute for Studies in Education, the Ottawa Rehabilitation Centre, Queen's University, Sunnybrook Health Science Centre, the University of Toronto, the University of Western Ontario, the University of Waterloo, and West Park Hospital.

Eight teams are curmetly in place, with the following areas of interest:

- Commmunications
- Hearing
- Mobility
- Prosthetics and Orthotics
- Psycho-social Evaluation
- Respiration
- Seating
- Vision

A diverse group of Ontarians is involved in this challenge to bring together scientists, consumers of assistive devices, industrial representatives, and health care providers from across the province in a program of research and development activities designed to meet the objective of bringing new assistive device technologies to consumers as rapidly as possible. The Hugh MacMillan Rehabilitation Centre (HMRC) has facilitated the collaboration, and serves as headquarters of the ORTC.

Rehabilitation research and development is part science but is at least in equal part an art of product design. In this latter part consumers' opinions are by definition the criteria of acceptability. Since there are fewer consumers of rehabilitation products than of other commercial products, and since there is less competition and hence less choice in the marketplace, the Consortium has created formats through which informed consumers can contribute and participate in the development of assistive devices.

OBJECTIVES

The Consortium's activities focus on assistive devices, which have been defined as "devices which assist individuals to compensate for physical deficits in school, work and community living." The Consortium is mandated both to research assistive devices and, through technological advancement, to contribute to the economic development of the Province.

Each of seven teams is currently involved in two major project activities, for which the emergence of products is intended. A Technology Transfer Unit interacts with the teams to facilitate technology transfer, and growth and development of Ontario industry in particular. A Psychosocial Evaluation Team, working with all of the other teams, assists in evaluation, encouraging and ensuring appropriate consumer involvement.

METHODS

To meet ambitious technology transfer objectives, a rehabilitation research group needs to nurture a product development culture that is similar to that of the commercial manufacturers whose partnership is sought. Researchers must "speak the language" of industry to some extent. Several factors have been identified as useful for a successful product culture:

- adopt a process model which takes into account marketing as well as technical development, and which reviews progress at identifiable stages;
- identify product champions early in the projects;
- draw upon the skills and experience of others who are closely allied to the organisation;
- provide infrastructural support beyond the traditional clinical or research models.

Stage	Technical Activity	Market Activity	Product Documents	Decisions
Generate Idea	Identify Ideas	Identify Ideas	Proposals, Sketches	Screening
Assess	Technical Assessment	Preliminary Market Assessment	Simple Schematics, Nomenclature	Preliminary Evaluation
Define Concept	Concept Design	Identify, Test Concept	Renderings, Instructions	Concept Evaluation
Develop	Product Development	Marketing plan	User Manual	Evaluation
Test	Prototype Testing	Prototype Field Test	Dealer Support	Evaluation
Trial	Final Design & Assembly	Test Market	Complete Product Description	Financial Analysis
Launch	Full Production	Market Launch	User Support	Post-launch

Activities at Stages of New Product Development

A product development process can be realised in seven stages (2). 1, Generate Ideas; 2, Assess; 3, Define Concept; 4, Develop Product; 5, Test; 6, Field Trial; 7, Market Launch. Each stage includes technical and marketing activity. A go/no-go decision separates each stage. Starting with broad freedom to generate many new product ideas, each succeeding stage is more costly and must therefore be more restrictive. The organisation should be prepared to shelve a product idea rather than develop it beyond what is reasonable from a cost/benefit standpoint. The documentation requirements of each stage are significant, as they form the basis of an effective technology transfer mechanism. This can make it easier for commercial collaborators to make their own assessments as to the value of a concept, and expedite the transfer of the technology to manufacture.

In the table above, each stage of development is shown vertically. Columns indicate the kinds of workassociated with each stage, in categories of: Technical and Market Activity; Product Documents; and Decisions.

The activity of identifying product or process champions is integral to the ORTC team structure. Strong commitment to the product concept can develop inside the Team Advisory Panels, where consumers, clinicians, marketers and researchers decide upon priorities, review projects and endorse new proposals. Consumer members of the Advisory Panels can help to draw other consumers in for focus groups, as well as bringing their own informed opinion into the design decisions as each project progresses. Similarly, members with marketing expertise can be influential from an early stage. Through their participation on the Management Committee, which reviews and approves projects with the guidance of the ORTC Advisory Board, team leaders have the opportunity to present on their own team's activities, and to engage in constructive criticism of the other teams.

The Consortium networking environment creates new opportunities for sharing skills and experience in technology transfer. First, each R&D centre within the Consortium has its own existing mechanisms for technology transfer, which can be enhanced and shared by the other Consortium members. Second, the traditional boundaries between types of disabilities are being lowered: the resulting cross-fertilisation of ideas and methods has proven to be a significant factor in several projects. Involvement in product development by Consortium members can follow several different routes: for example, one can work with fabricators to make a low volume, service intensive product to be used by one or several clinics; or work with industrial partners on a potential high return product, from the early idea assessment stages; or hand over development to an industrial partner at the end of concept definition. The choice of path depends on many factors, and it is important in managing technology transfer to focus on how each of those involved can benefit from following a particular route. In this regard, hindsight is 20:20. The opinion of someone who has made these decisions before, and who is committed to the organisation's goals, can be invaluable.

Studies of product development have identified the need for an organised plan, identifying discrete stages of the process, to contain costs and to demonstrate achievement of specific goals. A Technology Transfer Unit (TTU), as part of the Consortium management support, can facilitate the attainment of product development goals. It can provide access to a shared base of experience and of resources for new product development, across the structure of scientific, engineering and psycho-social research in assistive device categories. Funds can be allocated on a cost-recovery basis to do work that has been identified as crucial to the commercial success of a well developed product concept. The potential for royalty paybacks to support further activities is a significant factor in the review process. The ORTC was fortunate in securing financial and advisory support at an early stage of this endeavour, from the National Research Council of Canada (NRCC). This federal government department continues to provide assistance for commercialisation through its Industrial Research Assistance Programme.

RESULTS

During its first two years a provincially funded programme of rehabilitation research and development has evolved a strong focus on new assistive devices. Several products which were on the market at an earlier date have been upgraded significantly; introduction of new products which otherwise would not have been developed, is now imminent; and licensing agreements for new assistive device concepts have resulted from the concerted efforts of several of the ORTC teams, and of the Technology Transfer Unit.

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ASSISTIVE TECHNOLOGY TRAINING: AN INTERDISCIPLINARY APPROACH

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Until recently, there has been minimal cooperation between technical and human service disciplines in the development and provision of assistive technology (AT) and virtually no interdisciplinary training programs (ITP). In 1992 a ITP in AT was initiated at Utah State University. The present paper describes the program, including disciplines represented, training experiences, AT products developed by students, and student evaluation of the program.

Background

The science and practice of developing devices and services to assist individuals with disabilities is referred to as assistive technology (AT). Traditionally, human service personnel such as occupation therapists, vocational rehabilitation counselors, special educators, and speech pathologists sought to obtain AT devices for the consumers with whom they worked. Many of these devices were developed for other purposes by personnel from technical disciplines such as mechanical engineering or computer science.. Later they were adopted or adapted for use by individuals with disabilities. Until recently, formal interdisciplinary cooperation between human service and technical disciplines in the development of AT has been extremely limited, and interdisciplinary training programs have been virtually nonexistent.

Objective

Develop an interdisciplinary training program in AT that marries technical and human service expertise in the development and delivery of AT, and increases the pool of available AT personnel.

Approach

Recognizing the need for increased cooperation among human service and technical disciplines in the development of AT, the Center for Persons With Disabilities (CPD) at Utah State University initiated an interdisciplinary training program in 1992. Seniors from a variety of disciplines, including electrical and mechanical engineering, industrial technology, computer science, communicative disorders, social work and special education, were recruited.

Students in the program participate in a variety of learning experiences. Through a series of weekly seminars they learn basic information about disabilities and assistive technology. Guest speakers include designers, manufacturers, and suppliers who give students a real world view of AT development and provision. Meetings with consumers allow students to obtain first hand information about disabilities and a personal perspective on individual needs for assistive technology. Through field trips and laboratory work students have opportunities to become familiar with a wide variety of devices. They also participate on interdisciplinary teams that work directly with hospitals, schools, nursing homes and independent living centers. These teams adapt existing technology, design new technology, train people to maximize their use of technology and identify funding sources for technology.

Results

Detailed syllabi outlining specific training experiences were developed for the three quarter sequential duration of the inter-disciplinary training program. Students rated their satisfaction with and the value of each experience, and commented on how they might be improved. In general, the ratings were very high. Detailed data will be provided and discussed as part of the interactive paper session.

Interdisciplinary student teams developed numerous innovative AT products for the consumers they worked with, e.g. a reasonably priced communication device incorporating new computer technology, a battery-powered toy car adapted with a joy stick that made a two year old with cerebral palsy independently mobile, etc. Photographs and detailed descriptions of these devices will be provided as part of the interactive paper session.

Discussion

Students are involved in a practical inter-disciplinary team approach which enables them to learn from each other. At the same time, consumers benefit from the students' combined efforts. Students from technical disciplines develop increased awareness of disabilities and broaden their information base for making career and community service choices. Students from human service disciplines gain first hand experience with technology that will benefit the consumers they work with throughout their careers.

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RERC ON TECHNOLOGY EVALUATION AND TRANSFER: PROGRAM ACCESS AND VALUE ADDED

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ABSTRACT

The RERC on Technology Evaluation and Transfer is a collaborative program involving consumers coordinating user trials, businesses performing market analysis, and a university-center conducting technical evaluations. The RERC is designed to add value to potential products for the assistive technology marketplace. Inventors, researchers and companies have multiple access points to the RERC's capabilities.

STATEMENT OF THE PROBLEM

A collaborative solution to the major problems in the assistive technology marketplace was reported previously (1). This collaborative solution is now implemented through the Rehabilitation Engineering Research Center on Technology Evaluation and Transfer (RERC-TET), at the University at Buffalo.

The RERC-TET follows the principles of Participatory Action Research by involving stakeholder in all aspects of the process (2). Researchers who develop and test, business people who market and sell, and consumers who purchase and use assistive technology, all participate in the evaluation and transfer of new assistive devices.

Also, the RERC-TET's long-range plan takes the policy of inclusion to a logical conclusion. The program will eventually become a community-based enterprise, directed by and for persons with disabilities, with continuing technical support from the research center, and marketing support from the business community. A not-for-profit corporation named AZTECH is the basis for this community venture.

This paper describes the RERC-TET's program, presents points of access for perspective users, and explains how the RERC-TET's capabilities add value to new assistive devices.

APPROACH

The RERC-TET's mission is to help prototype assistive devices reach the marketplace by demonstrating their value through technical, consumer and market evaluations, and by identifying commercialization partners willing to turn the prototype into a product for the marketplace. Anyone with a prototype assistive device is eligible to participate. Inventors, researchers and companies are invited, while persons with disabilities are especially encouraged to participate.

The RERC-TET has a five phase model for performing this mission. For a small application fee, the project team will assess a prototype's commercial potential by examining its technical function, consumer value and market potential (Phases I and II). If the prototype shows promise, the RERC-TET will negotiate an agreement with the inventor to conduct further evaluations and seek commercialization partners (Phases III, IV and V). These additional phases are conducted at the sole discretion of the RERC-TET's management team. At the same time, the inventor can decline to participate further. These five phases are described below.

Phase I. Intake and Screen. Phase I is the point of contact for The RERC-TET. Phase I determines if the contact from an inventor, researcher or corporation fits the program. For example, the RERC-TET only works with new ideas developed into a prototype device. Callers with only ideas for products are referred to national programs working in those specialty area of technology. Callers seeking investment in a commercial product, or callers with inventions that clearly duplicate devices already in the marketplace, fall outside the project's scope. Callers in Phase I who appear to have a new prototype assistive device, are invited to complete a questionnaire on the device's background and submit it along with the prototype device as a candidate for the Phase II evaluation.

Phase II. Concept Review. Phase II involves a fairly intensive review of the prototype device, focusing on the device's potential value to consumers. Potential value is emphasized over present value because the prototype submitted may lack sufficient refinement to immediately demonstrate its full value as a future product.

Phase II has two steps. The first step is an initial review by a standing committee of a rehabilitation engineer, a business analyst and a consumer. This committee examines the prototype device and supporting documentation, to determine if the device is technically feasible, has functional utility, and is different from current products. If not, the application, prototype and fee are returned to the inventor with a referral to other resources.

In Phase II's second step, the marketing team investigate the device's ownership, development history, patentability and marketability; the technical team evaluates the devices function, safety and operating requirements; and the consumer team conducts focus group interviews on functionality, usability and appropriateness. The RERC-TET also searches for a commercialization partner, without revealing any proprietary information about the device. Responses provided important feedback about the device's value in the marketplace.

Phase II concludes with the inventor receiving a summary report from these analyses, including a recommendation about the device. This report concludes the RERC-TET's obligation for the application fee. Additional work is performed under a separate agreement with the inventor.

Phase III. Research and Development. If the prototype device demonstrates conceptual potential but still needs significant modifications to meet the needs of marketplace, it is considered an alpha prototype. The RERC-TET may propose an agreement to perform the work necessary to generate an improved version of the device considered a beta prototype. Developing a beta prototype typically involves initiating any appropriate legal protection over the device, performing the marketing and technical work outlined in the Phase II evaluation, verifying the device's safety, then involving multiple consumers in pilot testing of short duration.

The research and development work is a substantial investment of time and resources. The RERC-TET may stop the Phase III work at any point where the device demonstrates an insurmountable deficiency. Devices developed into beta prototypes that receive positive reviews by consumers, are then presented to potential commercialization partners. Either an external organization will agree to commercialize the device, or their feedback may prompt additional modifications.

Phase III concludes with the beta prototype and supporting documentation available for commercialization. The RERC-TET and the inventor will then decide to continue working together or end their partnership.

Phase IV. Prototype Evaluation. Devices developed to the beta prototype level are eligible for Phase IV. These devices may come directly from Phase II, or first move through Phase III. Prototype evaluation requires first constructing multiple copies of the device, then conducting extensive evaluations to determine how well the device functions as a consumer product.

For example, the technical team uses multiple copies to tear down, burn in and wear out. The consumer team uses multiple copies to conduct extended (multiple week) user trials involving test sites representing various demographic, geographic and climatic conditions. The marketing team uses multiple copies in presentations to potential investment or commercialization partners.

Phase IV should end with a transfer of the assistive technology to an outside entity. If transfer does not occur but the RERC-TET is convinced the device has adequate value for consumers, the final option is Phase V.

Phase V. Device Production. The RERC-TET's community-based business entity, AZTECH, may elect to product a device locally. In this case, AZTECH would pursue the resources to capitalize and implement a start-up company. Phase V is reserved for devices serving an important function but that cannot reach the marketplace any other way.

IMPLICATIONS AND DISCUSSION

The RERC-TET identifies, secures and communicates information on the functional value of new devices. Most inventors lack access to the technical, business and consumer networks capable of delivering this information.

Access to the RERC-TET. Any individual inventor or researcher, and any corporation has direct access to this program via telephone, fax or mail. If the program does seem appropriate, the inventor is sent an application package which is available in alternative access formats. The inventor is asked to return the application package and a functioning prototype with minimal delay. The inventor must also submit an application fee of fifty dollars, although a waiver is available for applicants with limited incomes. If the RERC-TET determines that the submission is not appropriate for whatever reason, all materials and the fee are returned to the inventor. The program also provides referrals to other agencies that may be able to help the inventor develop their concept or device.

The RERC-TET conducts the entire Phase I and Phase II process at no additional cost or obligation to the inventor. The Phase II information helps everyone realistically appraise the potential value of the prototype invention. The RERC-TET team and inventor jointly determine if the device moves to the later phases.

Researchers, corporations and consumer agencies can also access the RERC-TET by participating in the evaluation programs. Every additional participant strengthens the national information network and presents additional opportunities for collaboration. The RERC-TET expects to rely heavily upon the combined expertise of the research, development, training and information programs funded through the National Institute on Disability and Rehabilitation Research.

Value Added by Program. Contrary to popular myth, building a better mousetrap is no longer sufficient to draw the world's attention. Forty years ago, the marketplace had adequate capital to underwrite the cost.of implementing good ideas. In the recent past, the marketplace was still willing to gamble on promoting a new product once the idea was reduced to practice. In the present economy, proof of concept is replaced by proof of market criteria. The burden is now on the inventor to demonstrate that a market exists for a new device. Any information that helps demonstrate that market enhances the potential value of the new device.

Every phase in the RERC-TET's program is designed to add value to a prototype assistive device. For example, the initial screening determines if an invention qualifies as an assistive device, and identifies competing devices already in the marketplace. The Phase II Concept Review generates information about the device's technical and functional capabilities and target markets, and elicits direct consumer and marketplace reactions to the device.

The Phase III Research and Development activity transforms a rough prototype into a pre-production model, by incorporating the modifications identified in Phase II and testing those modifications under controlled local conditions. The Phase IV Prototype Evaluation work verifies prior work through nation-wide testing under all anticipated conditions. Phase V actually initiates production, which hopefully generates sufficient sales to generate interest from other firms in the marketplace.

The RERC-TET is available to pursue any arrangement that makes useful assistive devices more available to persons with disabilities.

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THE VA REHAB R&D TECHNOLOGY TRANSFER PROCESS

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ABSTRACT

The Department of Veterans Affairs (VA), Rehabilitation Research & Development Service's (Rehab R&D) Technology Transfer Section (TTS) screens the products emerging from rehabilitation R&D, primarily sponsored by the VA. Requests involving non-VA funded development are also reviewed to identify products or techniques that may meet specific VA needs within one of the priority areas: Prosthetics/Amputations/ Orthotics; Spinal Cord Injury; Communication, Sensory, and Cognitive Aids; and, Aging. The TTS is responsible for the design and management of a systematic process to validate proven rehabilitation R&D findings and progressing the successful outcomes into clinical use, product manufacture, and commercial availability. The ultimate goal is for timely transition of prototypic development into commercially viable products and techniques that can be readily available to benefit veterans and non-veterans with disabilities. Through national information dissemination of evaluation results, the TTS contributes knowledge about new products and techniques.

BACKGROUND

Technology transfer has been defined many ways. Much of what is understood about the process involves the exchange of information (1). Most technology transfer programs tend to focus on technology licensing and cooperative R&D which is understandable since these two activities involve transfer of intellectual properties (2). This paper describes a method of technology transfer that facilitates the progression of products borne out of the R&D arena into an objective environment that incorporates aspects of manufacture, evaluation, and, if deemed appropriate, availability in the marketplace. Based upon this process, technology transfer is viewed as a transformation of knowledge into successful new products and techniques (3) that are affirmed to be functional, safe, and effective for use by veterans and non-veterans with disabilities.

OBJECTIVE

The mission of the VA Rehab R&D is to support an intramural R&D program for improving the quality of life of veterans with disabilities. Non-VA funded requests are also reviewed according to selection criteria for acceptance as a technology transfer project. The end result is realized in the availability of products and techniques that can provide greater functional independence for the veteran and non-veteran populations. To support this mission and provide for prompt transfer of promising products and techniques into commercial production and clinical use, the Rehab R&D established the TTS.

To fulfill its primary role of making effective products and techniques available to veterans, and others, who may benefit from the technology, the TTS employs a systematic process that involves the developer, a manufacturer, VA Central Office (VACO) Service Director(s), and clinical test sites.

METHOD

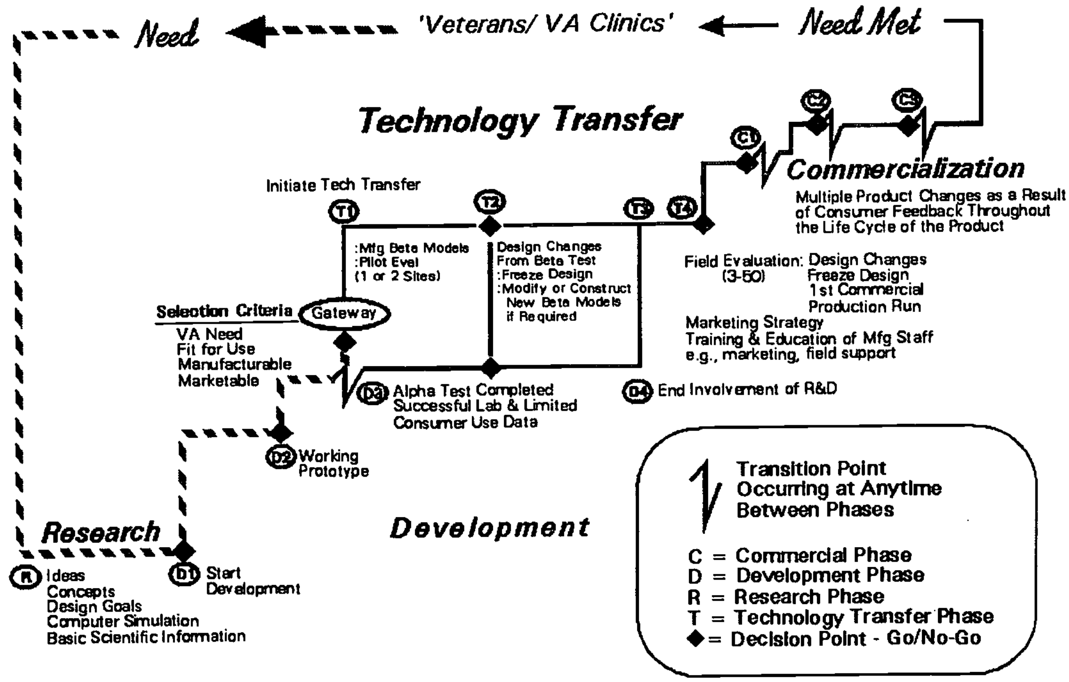
Activities and phases of the technology transfer process will be discussed using the schematic illustration on the next page.

Once the research idea/concept **(R)** has moved into development **(D1)**, the outcome is usually a working prototype. Internal testing and evaluation to demonstrate the feasibility of the new (alpha) device or technique is accomplished by the R&D principle investigator (PI). Design changes to the alpha model may be necessary based upon incoming data from the developer's testing. The working prototype **(D2)**, or alpha 2 model, would have completed successful laboratory and limited clinical trials prior to entering the technology transfer process **(D3)**.

It is at this juncture that the R&D PI submits a Request For Evaluation (RFE) to the TTS. The RFE elicits specific information that is used to review the appropriateness and readiness of the development as a TTS project. Receipt of a completed RFE officially commences the technology transfer process. This is followed by a peer review using the following selection criteria **(Gateway)**:

- **VA level of need/level of interest:**
  - a) <u>Product/technique classifies within one of Rehab R&D priority areas -</u>
    - 1) Prosthetics/Amputation/Orthotics;
    - 2) Spinal Cord Injury (and other disabling neuromuscular disorders);
    - 3) Communication, Sensory, and Cognitive Aids; and
    - 4) Aging.

TECHNOLOGY TRANSFER PROCESS



b) Product /technique should improve treatment, management, and rehabilitation of veterans as identified and verified by one or more of the following:

1) Appropriate VACO Service Directors;
2) VA Service Chiefs and/or clinicians recommended by Service Directors;
3) Veteran Service Organizations; and
4) Available VA statistics.

- **Fit For Use**

a) Alpha testing successfully completed on working prototype(s) to include:

1) Lab testing against recognized standardized tests for the following: safety issues and performance specifications.

2) Successful (limited) consumer use: **Minimum clinical data** (1 -2 subjects) from developer/ manufacturer (If all other criteria are met, this category usually requires a Pilot Evaluation); **Adequate clinical data** (3 or more subjects) from developer/manufacturer (If all other criteria is met, this category usually leads to a national, multi-center evaluation.

- **Manufacturable/Pre-Commercial**

a) Ready for manufacturing pre-commercial (beta) models as demonstrated by:

1) Adequacy of performance specifications, functional description, and illustrations.
2) Legal issues resolved or in progress i.e., patent rights, license to manufacture, CRADA, public disclosure, and royalties.

- **Marketable**

a) Market potential is judged in terms of the following: Percentage of target population (veteran vs non-veteran) that is likely to benefit from actual use of the product or technique; Competitive products vs major advantages of developed product; Cost to manufacture and market price; Training requirements to successfully transfer product or technique to routine use; and Service requirements.

Once the RFE peer review is complete and responses are positive, the TTS will formulate and submit a recommended plan of action, including budget support, to the Director, Rehab R&D Service. Approval at this level commences the manufacture and evaluation phases **(T1)**. A manufacturer is identified for the initial tooling, and engineering required for fabrication of the first production prototypes. As part of the procurement contract, the manufacturer is required to provide a statement of commitment to market the product or technique pending successful outcome of the evaluation. Allocated funds are transferred to the contracting VA Medical Center for manufacture of pre-commercial (beta) models.

Upon completion of manufacture, the beta testing and evaluation (T2 -T4) can commence. Based upon the extent of clinical data reported in the RFE by the R&D PI, a pilot study (approx. 3 months duration at 1 or 2 sites) may be necessary in order to generate additional data to support proceeding to a national, multi-center evaluation. The TTS collaborates with the appropriate VACO Service Director for selection of participating evaluation sites within the VA. The objective of the clinical evaluation is to validate the following areas: safety, effectiveness, reliability, benefits for the intended user, and the degree of commercial readiness of the product or technique. Depending upon the complexity of the project, it is oftentimes required that the TTS project manager make several on-site visits to the participating medical center to review protocol requirements for implementation, and provide staff training. During the course of an evaluation, data may indicate a technical problem which will necessitate a major design change in the beta model. It is at this juncture that a "freeze" is put on the evaluation. The developer and manufacturer must decide upon the appropriate modification(s) to resolve the problem. The revised beta models are then redistributed for continuation of the evaluation. The revision(s) would be incorporated into the commercial version. For example, at mid-point of an evaluation of the Synergetic Prehensor (a myo-electrical controlled, powered upper extremity prosthesis) subject data indicated a problem with grip force and reliability. A recall of the beta models was performed to incorporate a redesigned backlock mechanism to improve pinch force and minimize jamming. Evaluation resumed and final subject data showed that the retrofit significantly reduced problems associated with jamming and pinch force. As a result of the information obtained in this study and the manufacturer's redesign, a number of improvements have been made to the production model.

The resultant evaluation data is analyzed by TTS and a recommendation is generated and submitted to the VACO Prosthetic Technology Evaluation Committee (PTEC) for final review and approval. If recommendation is to proceed to commercialization and receives PTEC approval, the TTS forwards this information and copy of final report to the Office of Acquisition and Materiel Management, VACO, and its National Acquisition Center in Hines, Illinois. The manufacturer also receives notification and copy of the final evaluation report.

It is anticipated, especially in the early commercial years but also through the lifetime of the product, **(C1 - C3)** that consumer use will result in further refinement to continue to improve functional advantages and reliability. New technology that fills a void may be deployed to select VA facilities to encourage its integration into practice. The TTS also disseminates information concerning the commercial availability of successfully evaluated products and techniques through Product Evaluation Data Sheets, publication of articles in professional journals, and presentations at conferences.

IMPLICATIONS AND DISCUSSION

For effective technology application there needs to be a mechanism in place that not only supports the research and development but is also able to bring to fruition proven, successful R&D outcomes that are ready to be accessed by persons with physical and/or sensory impairments. It is realized that this is not a simple but complex process that requires a well-managed, purposeful plan of action. As part of the VA Rehab R&D Program, the TTS orchestrates an active approach that incorporates manufacture and evaluation (subject usage) early in the planning phase thus fulfilling two important areas: 1) "locking in" a manufacturer committed to supporting the product or technique in the commercial market and 2) gleaning clinical evaluation data from an objective environment that can be used to validate and enhance function and reliability of the product or technique. This process affirms user benefits and application, and generates a market opportunity for the final product or technique. Only through concerted efforts in networking and communication by those who effect varying technology transfer approaches and models can we remain focused on the exigent need for improving technology transfer practices and increasing the availability of commercial products designed to ameliorate the lives of persons with disabilities.

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PRODUCT DESIGN FOR PEOPLE WITH DISABILITIES: A NEW GRADUATE COURSE AT THE UNIVERSITY OF TENNESSEE MEMPHIS

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ABSTRACT

A new graduate course on Product Design for People with Disabilities has been developed in the Biomedical Engineering Department at the University of Tennessee Memphis campus. It is a project course which requires the design and prototyping of a device or system to meet a specified need related to a particular disability and activity. While focused on assistive technology, it is meant to teach lessons regarding design of human-interactive products which are generalizable to mass-market devices. Its lecture content covers a broad range of topics related to disability, design methods, and relevant technologies. The location of the BME Dept. on a "medical campus" offers the advantage that end users of assistive technology and expert providers of rehabilitation services are on hand to provide lectures, consultation, and design evaluation.

INTRODUCTION TO THE COURSE

Product Design for People with Disabilities (PDPD) is characterized by an unusual combination of features:

• In a single academic semester, students design and prototype working assistive technology to solve a problem which has not been solved by current commercial products.

• Students work in teams and are graded according to team performance rather than individual contributions.

• The course is taught in classroom and shop space at the UT Rehabilitation Engineering Program. This provides the course students with complete immersion in an environment populated by potential end users of their work and service providers — as well as the engineering faculty.

• Outside experts including users, practitioners, payers and potential manufacturers are directly involved in the evaluation and refinement of students' concepts and designs throughout the course.

• Lectures from several BME faculty members and visiting speakers provide the disciplinary breadth necessary to teach topics as broad as rehabilitation engineering and design.

• Design projects are chosen in part for their integrative pedagogical value; they require students to combine what they've learned in class work — with little regard for disciplinary boundaries — as well as their practical experience as users of technology and manipulators of the physical world.

• Marketing, legal and entrepreneurial issues are also important parts of the syllabus.

BACKGROUND

PDPD is being offered for several reasons. Most obviously, the Biomedical Engineering Department at UT Memphis is in the process of developing a graduate curricular track and research focus in Biomechanics and Rehabilitation Engineering (BRE). Three members of the faculty, including one with an endowed chair in rehabilitation engineering, focus their teaching and research in this area. To accommodate the interests of a variety of students, current and future course offerings will cover the range from reductionist description of human organ systems and their modes of failure to design of marketable technology to support function in activities of daily living. PDPD addresses the latter part of the spectrum of BRE activities.

In addition, the BME Dept. as a whole is placing unusual emphasis for an academic program on conducting and teaching biomedical engineering *design*. For example, in addition to BRE, several BME faculty in the area of medical imaging are developing dramatically improved approaches to making x-ray images. In engineering graduate programs, including biomedical engineering, an emphasis on the practice of design as an academically worthy endeavor continues to be uncommon. PDPD is one of the current or planned courses which establish this department's commitment to teaching biomedical engineering design.

Further, this course provides one of the major mechanisms for interaction between the UT Memphis Rehabilitation Engineering Program (UTREP), of which the author is the Director, and BME students and faculty. The therapists and technical staff of the Program deliver assistive technology services in the areas of seating, computer interfacing, augmentative communication and job accommodation. They and the consumers they serve in effect provide an in-house informal consultation service for the PDPD students, one which is typically impossible to obtain on engineering campuses. Their involvement in problem formulation and design evaluation insures that the students' designs are constrained and informed by the "voice of the customer". Accessibility of this community to the students is enhanced by conducting both the classroom work and fabrication activities in the UTREP building.

From the perspective of the Rehabilitation Engineering staff, the opportunity to teach and advise engineering graduate students also has value. These students' knowledge of technology and the perspective from which they ask questions can lead to the formulation of new ideas for assistive technology and rehabilitation service delivery. This has value to the Program since conducting r&d directed at advancing particular areas of assistive technology is a major part its mandate. Some of the same students who become involved with UTREP through the course will be conducting their thesis projects in rehabilitation engineering via grants awarded to the Program.

The greater Memphis industrial community also offers a supportive environment in which to teach PDPD. This area is home to Smith and Nephew Richards, Danek, Wright and Shering Plough, all of which develop and manufacture products for the practice of orthopaedic rehabilitation. Existing contacts between members of these firms' research staffs and members of the BME faculty facilitate informal involvement of these companies in the new course. In particular, advice and lectures from their staff on the constraints imposed on design by manufacturing, marketing and medical device approval procedures is readily available.

The conviction that small groups of talented but inexperienced students can make tangible progress in solving challenging rehabilitation design problems in a short period of time is based on the experience of the BME faculty with related teaching efforts at other universities. In particular, the author regularly introduced assistive technology projects into the required Mechanical Engineering Department senior design course which he taught at MIT. In one term, for example, each of four teams of twenty five students designed and prototyped completely new equipment for equestrians with paralysi. One example was a mount-dismount lift, specialized saddle, and joystick interface to the reins for quadriplegic riders.

DETAILS OF COURSE CONTENT AND FORMAT

In its present form, salient details of the course include the following:

- There are two lectures and one recitation section each week during a fourteen-week term.
- The project is defined only in terms of a desirable activity and a specified disability. Defining what the problem is and narrowing the scope of acceptable solutions, i.e. the phase which comes before conceptual design, is an essential part of the process the students are expected to experience.
- There are three major deliverables: a list of the design goals in the language of the intended users and a matrix which translates these into engineering variables; a proposed selection of team's best conceptual design represented as drawings and text; and a first-pass operating prototype of the device presented and documented for a faculty and community audience.
- Students are organized into independent teams of between 8 and 16 students, depending on course enrollment. Each team undertakes the complete assignment and all its members receive the same grade.
- Upon submission of the conceptual design from each team, a rapid evaluation is conducted by outside experts including potential users. Their comments become the basis of the next lecture and are used to guide design revisions prior to detail design and prototyping.
- Lecture content typically includes design methods, e.g. brainstorming, concept comparison charts and "QFD" methods for translating customer preferences into engineering variables; estimation for feasibility determination; graphical communication; a survey of current assistive technology and disability categories; generic design topics including reliability, safety, liability and patents; modeling of relevant areas of human function to guide design decisions; prototyping methods; group management methods and tools; and technologies relevant to the specific project.
- At this writing, the project in the Spring of '94 is the design of a "room-cruiser" for non-ambulatory toddlers with neuro-muscular disabilities. It is intended to utilize any movement the child can produce to provide propulsion on a flat floor. It facilitates exploration of his/her environment despite the absence of coordinated lower limb motion.

RATIONALE

The central notion of design project courses is not new and the rationale which applies in traditional disciplines appears to apply as well in rehabilitation engineering; design is a complex iterative process made up of numerous skilled creative and analytical activities. The process can be learned and personalized only through experience. This observation also provides one rationale for carrying the experiential learning of design through the prototyping phase. Another is the powerful motivational value, invariably noted by students, of a tangible outcome which can be demonstrated — not just drawn or described — to others.

The decision to organize the course around student teams was based on the observation that that's the way product development actually happens in industry. A typical undergraduate engineering education places enormous emphasis on individual accomplishment and encourages competition among individuals. This offers poor preparation for working in industrial teams, especially given the current emphasis on "concurrent design" and the organizational demands of shared responsibility for quality.

In presentation of the senior design course at MIT, it was found that the importance of sound team organization for the success of a product is also emphasized by requiring the fabrication of a prototype. Failure of team decision-making and coordination results in design flaws which are much more apparent when the design is brought to the point of physical implementation.

The particular project chosen for the current presentation of the course was meant to exploit UTREP expertise in seating and mobility. The "reality" of the project for the students is also enhanced by the possibility that it could result in new technology — perhaps further developed with grant funds — which would be prescribed experimentally and evaluated as part of Program service delivery.

The BME Department must meet the educational needs of those of its students who are motivated primarily by an interest in design of medical and other human-interactive products rather than a narrower focus on disability-related applications. Further, many of those students who do currently specify rehabilitation engineering as their intended professional specialty are likely to change tracks more than once in their careers and would therefore benefit by a course with broader applicability. For both of these reasons, it is important to note that reflection on the author's experience using assistive technology projects in mechanical engineering design courses suggests that there are several ways in which design of assistive technology effectively conveys many generalizable lessons. These have been discussed at greater length elsewhere [1] but a few are excerpted here:

• A real design task is almost never like "the problem at the end of the chapter"; it demands application of a broad range of disciplines and arts because that's they way the natural world and the marketplace are. This multidisciplinarity is particularly evident in design of assistive technology. Design of adapted control interfaces for computers, for example, had better take into account linguistic knowledge, learning theory, the mathematics of codes, and research-based models of human motor control, *in addition to* the "usual" range of topics central to interface design for mass-market computing.

• Another basic lesson taught to engineering design students is that they generally make poor models of their intended customers; in other words they must find out what their market wants rather than assuming that they can draw useful conclusions from their *own* preferences and needs. This becomes particularly clear, for example, to students designing an independent eating system for diners with quadriplegia. These consumers are so dramatically different in their physical capacities that students realize that they can't assume anything about less obvious characteristics such as how they trade off independence of function against simplicity and economy of the device.

• We also want our students to learn from their design-projects courses that the "soft" engineering considerations — for example comfort, ease of learning, and ergonomic efficiency — are in fact really hard. Design of products for people with reduced capacities makes it particularly clear that these considerations must be addressed carefully if an invention is to succeed in the marketplace.

• If a student ends up working for Boeing, for example, he/she will be professionally preoccupied with "human-machine systems" such as the performance of the combined attributes of a human pilot and a high speed jet aircraft. He/she will discover that what matters is how well the designer arranges for a match between the operator's task and the operator's abilities, a lesson that is taught particularly well by designing assistive technology since the designer's attention is drawn to the operator's abilities by the fact that they are so obviously different from his/her own.

• Students destined to be involved in product design need to learn that a successful product must "win" both for its objective performance and for the pleasure the user derives from its aesthetics. The importance of both of these determinants of success is emphasized in design of assistive technology since performance is critical since for elimination of functional handicaps *and* aesthetics is also crucial since the way a person with a disability perceives him/herself and is received by the world is very sensitive to the way s/he looks.

• Finally, we teach design students that one of the reasons that the American auto industry had lost ground to Japanese manufacturers is that Detroit had not paid sufficient attention to the diversity and rapid change of tastes, preferences and driving circumstances of its intended customers. Assistive technology offers students a particularly vivid example of the need to design products which are modular or field-programmable or customizable on the assembly line to accommodate the extreme range of needs and abilities that characterizes its market.

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RR&D'S BAG OF TECHNOLOGY TRANSFER TOOLS

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ABSTRACT

One of the most challenging goals of the Palo Alto VA's Rehabilitation Research and Development Center (RR&D) is the transfer of its laboratory prototypes to companies for manufacture. Without a purposeful program of technology transfer, devices developed here would remain mere research curiosities and would not benefit disabled veterans.

Despite past obstacles to technology transfer, there now exist a variety of tools and incentives that can promote commercialization of RR&D's prototype devices.

BACKGROUND

Commercializing the Center's rehabilitation products is a formidable task since many of them face a limited market, are costly to develop, are sold to people with limited financial means, involve third party payers, and are subject to many Federal regulations. For these reasons, investors and manufacturers are often hesitant to address this market, even though the need for the product may be great.

For RR&D, the process of commercializing a prototype device requires a substantial commitment of manpower and resources. Contacts with potential manufacturers must be developed and maintained; advanced prototypes and enhancements of the project may be required for demonstration; supporting documents and promotional materials must be developed and produced; and patentability and marketability must be investigated.

OBJECTIVE

An important part of RR&D's mission is to develop assistive devices which will directly benefit disabled veterans. Since the VA cannot by law manufacture the devices developed at the Center, it must rely on industrial companies to build and market them. The goal of technology transfer therefore, is to promote RR&D's prototype devices to commercial businesses, move the expertise embodied in the prototype to an interested company, and to often work with that company to insure a manufacturable and marketable product that can serve individuals with disabilities.

METHOD / APPROACH

Over the past seven years the repertoire of tools that facilitate technology transfer has increased dramatically. Despite the existence of these tools, there is no simple protocol that is universally applicable to every technology transfer situation. In each instance, a different complex mix of preparation, documentation, demonstration, contacts, and serendipity is required. Some of the tools and methods available to RR&D are described below.

VA Technology Transfer History

A Technology Transfer Section (TTS) has been formed within RR&D to accelerate, encourage and promote the transfer of technology, including the commercialization of RR&D prototype products (now numbering thirty-one) through collaboration with industry. This group serves to advise, organize, supervise, and coordinate all of the Center's TT activities. It also serves as a resource on these matters to other investigators within the Center, explores and maintains contacts with industry, arranges workshops, prepares agreements, and carries out negotiations when appropriate.

TTS has now formulated a strategy for technology transfer that comprises three programs: 1) Recruitment - identifying potential new products from within the Center, 2) Evaluation - identifying criteria and methods for screening projects for commercial potential, and 3) Availability - developing and maintaining manufacturer contacts, disseminating information, and negotiating agreements or licenses.

Within TTS a systematic way to evaluate the technology transfer potential and commercial feasibility of RR&D's projects has been developed. The prototype product's value in each of the following areas is determined: 1) its value to a potential licensee including potential market size, risks involved, and competitive advantage offered; 2) its value to the user or purchaser including importance of need, satisfaction of need, and alternatives to the product; and 3) its value to the VA including concurrence with the Center's mission and existence of champions inside and outside the Center.

A first round of assessments on six projects has provided valuable feedback about the evaluation process, as well as giving a common reference for discussion about specific projects. Project values which scored low in the assessment process can now be seen as targets for improvement. For example, the value to licensee might be rated low because of small potential market size. This can provide impetus to the investigator to find wider applications for the particular technology.

A Technology Transfer Advisory Board has been formed by TTS to provide broad expertise in all facets of technology transfer. It consists of twelve non-government specialists in the fields of technology licensing, patent and Federal law, marketing, third party payers, product design, venture capital, rehabilitation medicine, rehabilitation service delivery, manufacturing, and business. The Board members have been helpful in suggesting new tactics and continue to provide business and marketing advice.

TTS has developed a working database which contains information on all of our projects, as well as information on the TT process. In addition, a database of VA decision-makers, funding sources and foundations, rehabilitation professionals, clinicians, engineers, potential manufacturers of RR&D prototypes, students, users, press and media people, and interested lay people is being maintained.

To increase the awareness of colleagues, users, manufacturers, health professionals, entrepreneurs, and others of RR&D's projects and products, the **On**Center newsletter is published two or three times a year. It highlights new developments and opportunities in technology transfer, reports on specific products or projects, and solicits ideas, suggestions, and inquiries about RR&D's work. The distribution of **On**Center has lead to numerous personal contacts that are the prelude to successful technology transfer. Five issues of the newsletter have been published and mailed to over 2500 individuals and organizations in the TTS database. In addition, RR&D routinely publishes and disseminates a Progress Report every two to three years. It describes all projects being undertaken in the Center's four program areas.

To assist in the technology transfer and subsequent commercial availability of promising devices and techniques developed at RR&D, the VA has established the Technology Transfer Service (VA-TTS) in Baltimore, MD. The VA-TTS funds commercial prototypes of RR&D's devices and evaluates them clinically within the VA system. Devices they approve may be recommended, prescribed, and purchased by the VA for use by disabled veterans. Three RR&D projects have employed this technology transfer procedure.

Legislation

The passage of the Technology Transfer Act of 1986 by the U.S. Congress authorized local Federal laboratories to negotiate and enter agreements directly with industry for the purpose of commercializing government technology. This legislation represents a significant change from the previous laws which essentially prohibited such collaboration. It offered the first real prospect for RR&D to participate actively in the commercialization of its products. Before that time, it was considered a conflict of interest for government employees to be involved in the commercialization of technologies developed in Federal laboratories.

Funding and Partnering

The Technology Transfer Act established a mechanism called the Cooperative R&D Agreement (CRADA) to promote and facilitate the transfer of technology from a Federal laboratory to private commercialization. It permits a private company to fund and work with RR&D toward the development, manufacture, and marketing of a specific rehabilitation device.

In addition to CRADAs, RR&D can also enter into collaborations involving the exchange of knowledge, facilities, or personnel where no money changes hands.

In 1982 Congress established the Small Business Innovation Research (SBIR) program to provide small business with the opportunity to acquire Federal R&D funds to stimulate the development and commercialization of technology for public and private benefit. Under Phase I of an SBIR competitive award, a small business can receive up to $100,000 for up to six months to evaluate the technical merit and feasibility of an idea, while in Phase II they can receive an additional $750,000 for up to two years to expand the Phase I effort and develop the technology in preparation for commercialization.

Under a funded SBIR project, both a small business and RR&D (serving as a consultant) can receive funds that support moving a research prototype out of the laboratory and into the marketplace.

The Small Business Technology Transfer program is similar to an SBIR, with awards of $100,000 and $500,000 for Phase I and Phase II respectively. It is intended to stimulate and foster scientific and technological innovation through cooperative research and development carried out between small business concerns and research institutions, foster technology transfer between small business concerns and research institutions, and increase private sector commercialization of innovations derived from Federal research and development. The participation of a federal laboratory is mandatory in an STTR and appears to be an ideal arrangement for a small company that desires to commercialize RR&D projects.

The FDA Orphan Drug Medical Device Grant Program appears to support technology transfer for medical devices for diseases and conditions that affect small populations or have little financial incentive to research. They will provide grants of up to $100,000 a year for up to 3 years for clinical trials for existing prototypes and a similar amount over two years for projects with additional development. Public and private non-profit and for-profit organizations are eligible to apply for these awards.

Palo Alto Institute for Research and Education (PAIRE)

PAIRE is a non-profit organization within the VA Medical Center that can administer funds from CRADAs, SBIRs, STTRs, and negotiated contracts that would be difficult to handle under existing circumstances. It can support the hiring of personnel, equipment purchases, and petty cash reimbursements required while working under these situations.

AZTech, Inc.

AZTech is a not-for-profit, community-based enterprise operated by the Rehabilitation Engineering Research Center on Technology Evaluation and Transfer under a grant from National Institute on Disability and Rehabilitation Research. The company will evaluate a prototype rehabilitation device for commercial potential, identify corporate partners and establish business agreements that are intended to move the product to market. Inventors (including those who use assistive devices), companies, and research centers are encouraged to participate in this program. A small application fee and a working prototype are required. [1]

Business Gold

The National Technology Transfer Center (NTTC) has developed an electronic bulletin board system called Business Gold, as an easy, convenient means of accessing information on the newest federally funded technologies. Updated regularly, the online system provides a new directory of Federal R&D laboratories and new Federal technologies available for commercialization, current Small Business Innovative Research solicitations, electronic mail facilities, Federal R&D information, and related announcements. Future enhancements include a conference calendar of technology transfer events, a publications list, and education and training opportunities. The service is free, and there are no online or report charges.

RESULTS

RR&D now has over eight years experience with technology transfer. Some of the lessons learned are:

1. Tech transfer does not come about quickly, even in the best of circumstances. It requires large doses of preparation, experience, and chance.

2. The time from transferring a working laboratory prototype to seeing a product on the market can be reasonably short if the company is small, adequately funded, and smart and thorough in its approach.

3. Hiring the RR&D developer is often critical to the small company's success. Even though the VA loses a valuable investigator, there may be no more effective means of fulfilling its mission to transfer its technology.

4. The movement of promising technology to industry offers the private sector valuable knowledge, expertise, and R&D effort which they might otherwise not be able to afford.

RR&D's successes include:

1) arranged for seven Center products to go into commercial production;

2) produced and distributed a technology transfer Guidebook authored jointly with a private company;

3) published five issues of **On**Center aimed at technology transfer professionals and potential manufacturers;

4) collaborated with VA Technology Transfer Service in Baltimore and with Gallaudet University in Washington to put field four Center products into field evaluation;

5) negotiated the following: two Cooperative R&D Agreements with private companies; one license agreement; a publishing agreement; and two agreements with private companies for patents and licensing;

6) filed twelve disclosures of inventions with VA's General Counsel in Washington.

DISCUSSION

Bringing a good project idea to the point of commercialization requires a concerted, long-term technical effort, several infusions of funding, and plenty of patience on the part of RR&D investigators.

Technology transfer is like gardening: no one can build a rose, but a good gardener can produce a better one by tilling the soil well, selecting the right seeds, getting the bugs out, and doing the right kind of fertilization, watering, and pruning.

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DESIGN ISSUES FOR PEOPLE WITH SPECIAL NEEDS - A STUDY WITH DRIVERS

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ABSTRACT

Design issues which are relevant for drivers with special needs were identified in a field study as part of the TELAID DRIVE II project. These design issues were classified under the following headings: User and Task Match Aspects, Usability Goals, Input Aspects, Output Aspects, and Physical Characteristics of the Aid. This paper presents an overview of developing design guidelines for drivers with special needs and describes certain key issues which are emerging. The study emphasises that many of these design requirements apply to all drivers, and also to the design of many products for people with special needs. Likewise, designing for special needs often makes a product easier for everyone to use.

INTRODUCTION

Drivers with special needs (or DSN) may require adaptations to make their driving easier and safer, including adaptable control aids (eg hand-controlled accelerator or secondary control levers for headlights), or mobility and car adaptation aids (eg swivel seats and aids to enter or leave the car). Advanced technology, applications including navigation and route guidance, travel and traffic information, emergency call, or collision avoidance systems, may also enable more people with special needs to drive by improving safety and performance, or simply through the confidence and security it gives them. However, a trend in new technology is to introduce alternative modes of input or output, eg voice control or sound output. Great care must be taken to prevent the future development of cars and advanced technology systems taking such a direction that those with perceptual impairments will *become* drivers with special needs, or that the driving task will become *more* difficult than before, leading to a decrease, not an increase, in driver safety.

The TELAID project (Telematic Applications for the Integration of Drivers with Special Needs) is part of the Advanced Transport Telematics DRIVE II programme of the Commission of the European Communities. TELAID's main objective is to apply developments in new technology to extend the range of assistance that can be given to drivers with special needs.

Using a systems approach, other types of aids were also included in the study, as the use of another aid might lead to a different type of performance or workload. A final product of the project, which ended its first phase in December 1993, is the development of design guidelines for aids for drivers with special needs. This paper presents an overview of these guidelines and describes certain key issues which are emerging.

Guidelines exist to assist fitters of car adaptations when making technical conversions to a vehicle to meet a disabled driver's functional requirements (eg 5). The 'Draft Code of Practice for In-Vehicle Information Systems' (1) covers key issues that must be considered when designing advanced technology systems that will be used by the driver while driving. However, car manufacturers, car adaptation manufacturers and research projects often do not have the resources to satisfactorily include the wide ranging needs of different impairment groups. As drivers with special needs are often closer to the limit of their abilities, the demands on good design become more explicit for them, and pitfalls of adaptation solutions may result in even more severe consequences (4). Therefore, guidelines are needed to ensure that DSN are included in the design process.

METHOD

The constraints, limitations and requirements of DSN were identified in a field study, following the 'Cascade Model' for data collection (3). Two tools were developed specifically by the TELAID consortium to collect comprehensive data:

- A comprehensive definition of the driving task to serve as a checklist, or structured interview. This list of components of the driving task totalled 11 main tasks, 73 sub-tasks and 165 prompts, to assist the interviewer to cover the required level of detail, ranging from steering and accelerating to planning a journey.
- A classification tool to identify the range of impairments which should be included in the term "Drivers with Special Needs". The classification was based on the *effects* of the impairment, rather than the *cause* of an impairment. The impairment groups included in the data collection were visual, reading,

hearing, speech, lower limb, upper limb, upper and lower limb, upper body, sudden loss of control, and cognitive.

RESULTS

This study had two major results:

- It highlighted components of the driving task which cause difficulty for each or every impairment group. This helped to identify the problem areas, driving tasks and target groups to investigate in the TELAID simulator tests (4).
- Problems experienced by drivers with special needs identified design requirements for existing or prospective aids, which formed the basis of the TELAID design guidelines for aids for drivers with special needs.

A full description of these design requirements can be found in TELAID Deliverable No. 6A (2). These issues form the basis of the TELAID design guidelines for aids for DSN, which will soon be submitted to the CEC in the final deliverables of the project. Only a selection of issues are given below because of their relevance not just for drivers, but for all people with special needs. They are classified under the following headings, cascading from high level categories of guidelines which can be broken down into lower level guidelines and specifications.

User and Task Match Aspects
These design aspects refer to how well the functionality of the aid or system meets the specific and often changing requirements of the user, and also how the user is supported in the performance of the required task. Take, for example, "Meeting the real needs of the user." With such heterogeneous user groups, these needs cover a wide range and may also be changing over time, due to degenerative or variable illnesses, either over the long term or the short term. People with variable illnesses may have reduced physical or cognitive abilities on certain days, due to anxiety, stress, or climate. For example, an arthritic driver may have particular difficulty in damp weather when using the secondary controls (eg for heating or directional signals), and designers should consider this issue when choosing the size, location, shape and sensitivity of the controls.

Usability Goals
These design aspects refer to how well the aid or system supports a particular user in achieving specified goals in a particular environment, effectively, efficiently, safely and comfortably. Take, for example, "Flexibility and Adaptability." To what extent can the DSN easily adjust an aid to suit individual requirements? Can users easily input or interpret output, or adjust the location of the input/output device, whether it be in the car or when using a control panel in the home? Those with mobility impairments may have problems adjusting a car seat, especially when full back position is required to get in and full forward position is needed to drive, and also when other people drive the same car. This design issue is also relevant in "smart home" technology, when, for example, a product like a telephone or remote control needs to be used - and accepted - not just by the elderly or disabled person, but also by other members of the family.

Input Aspects
These design aspects relate to how the user communicates with or manipulates the aid or system, eg through writing, speaking, or physically operating the controls. Take, for example, "Choice of input mode and workload on residual abilities." Is the driver able to choose the most appropriate mode of input to cater to individual needs (eg voice or tactile, novice or expert facilities)? The aid or system must not impose an overload on residual abilities or on one capability trying to compensate for another. When a paraplegic driver uses hand controls for all the primary and secondary driving tasks, do the upper limbs have to work excessively to compensate for lower limb impairments? The introduction of any new technology in the vehicle must consider the already heavy workload imposed on that driver. Alternative modes of input and output should be investigated, for example, voice activation for secondary controls, bright sunshine (eg for putting down the sun visor), and moisture (for activating the windscreen wipers). Users must be able to operate controls effectively and safely without using total available force or controlling strength. If constantly working to the limits of one's capacity, a person with special needs would be unable to cope with emergency situations, whether it be in the car, in the home or anywhere else.

Output Aspects
These design aspects relate to how the user receives or interprets information from the aid or system, eg through reading, listening, receiving tactile messages, or viewing graphics on a display. Take, for example, "Choice of output mode and workload on residual abilities." Is the driver able to choose the most appropriate mode of information presentation to meet any special requirements (whether it be visual, auditory, tactile, or other)? As with the input aspects above, the product or system must not impose an overload on residual abilities or on one capability trying to compensate for another. The visual channel, for example, must not become overloaded for hearing impaired people, and the

tendency to introduce voice output in cars might lead to some people *becoming* drivers with special needs.

Physical Characteristics of the Aid
These design aspects are the tangible characteristics of the object, eg whether a slippery surface texture facilitates or hinders performance of the task. Take, for example, "Texture of surfaces." To what extent does the texture of the object facilitate or hinder performance of the required task? For example, wheelchair users find that slippery surfaces make it easier to get in and out of the car, and some drivers interviewed even carried a plastic carrier bag with them to slide in and out. Possible reflections or glare on surfaces, controls or displays might also hinder performance. Such glare could cause discomfort or even further impairment, and must be considered in any system development, whether it be in the home or in the car.

DISCUSSION AND CONCLUSIONS

Problems experienced by DSN have yielded recommendations for improvements in design which will better utilise the residual capacities of drivers with special needs and optimally support the performance of the driving task. These recommendations form the basis of design guidelines for aids for DSN, a selection of which have been discussed above.
Although this paper emphasises *drivers* with special needs, these design requirements should apply to all drivers, and likewise to the design of many products for *people* with special needs. However, it is a common error to assume that the design requirements of elderly or disabled people are unique. Many of us may at times, or will in the future, experience some difficulty with, for example, inserting the key into door locks, fastening seat belts, operating dashboard controls, using the handbrake, or parking. Consider the needs, for example, of people with young children or heavy shopping, small drivers, or those suffering from even a temporary stiff neck. So, if all designers would design for *everyone*, this will help vast numbers of the able-bodied population as well.

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USER INVOLVEMENT IN ASSESSMENT AND USER INFLUENCE IN STANDARDIZATION OF CONSUMER PRODUCTS AND ASSISTIVE TECHNOLOGY

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ABSTRACT

When assistive technology and consumer products are standardized or when they are assessed for general suitability, the work is traditionally carried out by professionals, e.g. therapists and engineers, whereas consumers are rarely involved in the process, even though they are the real experts concerning their own requirements and needs.

The Danish Centre of Technical Aids for Rehabilitation and Education enjoys a close cooperation with the Danish organizations of disabled persons, so it was natural to involve users from these organizations when entering into the fields of assessment and standardization.

Two projects were implemented: one on the assessment of conventional telephones and one on user influence in international standardization. In both cases vital knowledge was gained from disabled users.

This paper briefly describes methods used in the assessment project of conventional telephones, and methods used and experience gained in the project on user influence in international standardization.

BACKGROUND

Traditionally, international standardization work has been carried out by manufacturers' technical consultants together with technical consultants from the regulatory and supervisory authorities. This may seem natural enough since up until now standardization has focussed on the technical specifications of products in order to ensure product uniformity and to safeguard against designs that may harm users or damage other equipment. However, user demands as to product functionability and easy operation continue to rise, and the acknowledgement that "technical" standardization is merely one element in standardization work is gaining ground. At the same time, manufacturers are becoming more and more aware of the fact that product functionability and easy operation constitute major competition parameters. Concepts such as functionability and easy operation are of special interest to disabled persons because as users, they make greater and more radical demands as to product user-friendliness.

In close cooperation with the Danish organizations of the disabled, the Danish Centre of Technical Aids for Rehabilitation and Education has participated in the work concerning assessment and standardization of conventional telephones.

OBJECTIVE

In cooperation with Danish user organizations, the Danish Centre of Technical Aids for Rehabilitation and Education will publish a catalogue of all Danish standard telephones rated in terms of suitability for disabled persons.

In addition, in close association with European user organizations, the Danish Centre is involved in the standardization of telephone keypads, so that disabled and elderly persons without difficulty can operate a conventional telephone keypad.

APPROACH

In association with the Danish organizations of the disabled, the Danish Centre has compiled an evaluation profile which has been used to assess the individual telephones in terms of suitability for the disability groups mentioned below. The evaluation proflie consists of approx. 60 assessment items, and under each item the following is described:
- -the reason for assessing the item in question
- -how the item is assessed
- -which assessment criteria must be observed
- -which disability groups are to assess the item, and questions asked
- -comments and observations
- -references

A user panel representing the following disability groups: the blind, the visually impaired, the speech impaired, the hard of hearing, the mentally disabled, and the physically disabled, has assessed each individual telephone and thus provided the basic information material for the catalogue. Furthermore, the telephones have been examined and rated by an interdisciplinary team of technical consultants and therapists.

The individual components and functions have thus been assessed upon the basis of concrete knowledge of the needs and requirements of the various disability groups. Assessment findings of handsets, keyboards, displays, ringing functions, operation keys, inductive coupling, tactile marking etc have subsequently been compiled in a joint report which provides a detailed description and assessment of each telephone with regard to the individual disability groups.

As a result of this work, the wish for an even closer working relationship with user organizations arose. The opportunity came in connection with a project under the European program TIDE (Technology Initiative for Disabled and Elderly People). The project is called HEART (Horizontal European Activities in Rehabilitation Technology). In a sub-study of this project, the Danish Centre will carry out a case study concerning user influence in European standardization. In this work, user organizations are involved in monitoring and controlling the study, so that users are able to influence the standardization process and thereby influence the result.

In other words the study will result in a useful and applicable method of ensuring user influence throughout the entire process of standardization work, at the relevant levels. In addition, the study will result in a draft standard of a product which will follow the usual procedure, including a public enquiry.

Experience from the work concerning the assessment of conventional standard telephones has shown that there is a need for the standardization of telephone keypads. After a round of discussions with relevant organizations of the disabled, it was decided that the subject of standardization would be telephone key size and key spacing, with the purpose of preparing a standard so that disabled and elderly persons without difficulty can use a conventional telephone keypad. Also, the subject of standardization has been approved by ETSI (European Telecommunications Standards Institute).

The first step of the study consisted in making enquiries at relevant Danish disability organizations to find out whether they could select representatives, i.e. experts from their organizations who would be interested in taking part in the study. Qualification requirements included a solid knowledge of the individual disability group's functional impairments and the consequences of these impairments. Furthermore, it was necessary that representatives were able to speak English as some of the work would take place in an international environment. All expenses in connection with the study were covered by the project. Two representatives from each of the following five disability groups were selected:

- mentally retarded persons
- persons with uncoordinated movements
- persons with reduced movement capabilities
- persons with visual impairments
- blind persons

The next step was to hold a training session for the representatives to ensure that they had a certain knowledge of the problems concerning the elaboration of standards.

After the training session, the actual work could begin. A control group was set up, consisting of user experts (the trained user representatives) and professional experts in standardization and disabled persons' accessibility to telecommuncations: therapists, technical consultants and sociologists. The task of the control group was to monitor the study to make sure that users have the necessary influence on the standardization process and thus also on the result.

The control group decided to follow a method based on an analysis of already existing products (in this case: telephone keypads) and the requirements disabled users have in order to operate them with the least possible difficulty.

However, a method based on mock-ups is equally applicable and can be used in connection with the standardization of future products.

The method will be presented to the European organizations of the disabled so that the control group may receive relevant comments and incorporate these in the final proposal for 'User Influence in Standardization'.

The analysis was carried out in the form of a user panel test of 12 different telephones. The 12 telephones are representative of approx. 60 different telephones selected from the European market. About 60 persons with specific functional impairments took part in the user panel test which included analyses of various keypad layout designs.

The material from the user panel test was then processed statistically and provided the background material for the elaboration of a draft standardization concerning telephone key size and key spacing.

DISCUSSION

The project is still in progress and does not end until September 1994. The project will be evaluated and the methodology applied will be discussed in organizations of the disabled, relevant parties of standardization work, and standardization bodies.

Since this study has been conducted as a case study concerning the standardization of a specific product, consideration must be given, among other things, as to how the method can be used in general in standardization work to ensure relevant user influence.

Several conclusions, however, may be drawn already:
- It is of great importance that users take an active part in standardization work. In order to ensure this, it is vital that organizations of the disabled are aware of standardization tasks so that user representatives are motivated and carefully selected.
- An introduction to standardization work, e.g. by training, is important so that user participants may gain an overall insight into standardization work and procedures.
- It is necessary that the organizations of the disabled regard standardization work as an important task and organise themselves so that it is possible for them to participate.
- In future, standardization work must be given financial support so that users from organizations of the disabled are able to participate when necessary.

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SIG-08
Sensory Aids

EYEWEAR THAT PRECISELY CONTROLS LIGHT INTENSITY LEVELS AT THE EYE

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ABSTRACT

The purpose of this project is to research, develop and evaluate eyewear that dynamically and "instantaneously" restricts the amount of light reaching the wearer's eyes to a preset level. Both Liquid Crystal (LC) and electrochromic technologies are being explored toward this purpose. A first LC engineering prototype is currently being evaluated, and the investigators intend to obtain an electrochromic prototype for evaluation by Fall 1994. Initial prototypes are being tested by a small, diverse population of subjects. Both clinical trials and mobility trials in structured outdoor urban settings are being employed. Results of these initial trials will be evaluated relative to optimizing the device design. Final, re-designed prototypes will be evaluated by a larger population in a more rigorous battery of tests. Results will be published and provided to potential manufacturers. An initial retail price of less than $250 is expected.

BACKGROUND

Persons with ocular diseases such as retinitis pigmentosa (RP), albinism, aniridia and achromatopsia have extreme problems with varying light conditions and can usually function effectively only under the most controlled lighting conditions. Other ocular diseases such as macular degeneration and conditions affecting the ocular media (e.g., cataracts, corneal dystrophy) have varying effects on retinal adaptation. Dark adaptation times as long as 30 minutes are not unusual [1].

For all persons (fully sighted as well as persons with low vision), a fairly narrow range of overall illumination is optimal. Too much or too little light results in dramatic reductions of visual acuity and a corresponding reduction of visual function [2]. However, the unimpaired person has a type of visual reserve (i.e., more acuity, more field of view, more contrast sensitivity, more light/dark adaptation, etc. than the minimum required by the visual task) [3] that gives this person the ability to maintain functional performance in less than optimal conditions.

A fully sighted person exiting a darkened theater into bright sunlight may squint, shade the eyes, look down, etc. until the eyes have adequately adapted (only a few minutes); however, this person *can* continue to function while adapting to the sudden change in lighting and *will* be able to avoid obstacles and negotiate curbs and stairs. But the low vision traveler, who does not possess this reserve, can*not* function under these circumstances.

The low vision traveler experiences two primary functional vision problems: detection of changes in terrain, such as curbs, and adapting to changing lighting conditions [4]. In a recent national survey, low vision consumers and their mobility instructors rank ordered their most serious orientation and mobility problems. "Changing environmental lighting conditions" was considered the most difficult mobility situation by both consumers and instructors [4]. "Drop offs," down curbs and steps, were reported as second most difficult. Persons with low vision were also found to confuse shadows of buildings and mailboxes with curbs and potholes. In terms of functional mobility, this confusion resulted in reduced travel speed and gait changes based on reactions to shadows [5].

Constraining the amount of light reaching the low vision person's eyes to a narrow, constant range might, in and of itself, provide a sufficient increase in acuity and contrast sensitivity to distinguish between a shadow and a "drop-off." In a separate article, the authors stated that "the use of absorptive sun lenses or individually prescribed illumination-control devices may alleviate some of this difficulty, but would not eliminate the variability in visual functioning brought on by ever-changing [rapidly changing] lighting conditions" [4].

Light- absorbing lenses are available and prescribed in a variety of styles, colors and levels of light transmission. But in order to adapt to a variety of conditions (bright sun, cloudy, indoor bright, indoor dim, fluorescent or incandescent lighting) it is necessary for low vision consumers to find a variety of absorptive lenses and illumination controls, and to constantly change back and forth among them—a cumbersome task at best. Photo-darkening lens coatings are also available and do provide a degree of accommodation to changing lighting conditions. However, the photo-chemical processes currently employed do not adapt "instantly" to changing lighting conditions, especially when going from bright sunlight into shadow—a particularly hazardous situation for persons with low vision. Further, the wearer has no control over this photo-process and cannot adjust it to constrict the amount of light passing through the lens to specified level.

The concept of "ideal retinal illumination level" emerges from the physical property of optimum stimulus threshold for the eye, which is dependent upon a variety of factors (such as ocular health status, age, and task). The dark adaptation curve—itself a statement of retinal stimulus threshold—is affected by pupil size, normal aging, stimulus size and location, and the presence of ocular disease. These variables modify the eye's ability to respond and adapt to changes in retinal illumination [6]. The consequences of changes in retinal illumination are many, including changes in color vision and in contrast sensitivity function (CSF) [7].

Therefore, the role of an eyewear device that could dynamically and "instantly" adjust to changing lighting conditions to maintain an "ideal retinal illumination level" would significantly contribute to the mediation of retinal function, especially in the presence of ocular disease.

RESEARCH QUESTIONS

Two research questions are to be answered by this research.

1. *If:* an eyewear device were constructed with the following specifications:
   (a) lenses that can be darkened/lightened to effect controlled light transmission at any light level between 2% and 45% transmission with the ability to dynamically change per cent transmission "instantly" (within 50 milliseconds),
   (b) sensors on the eye-side of the lenses monitoring field-averaged light levels reaching the eye,
   (c) a user-adjustable feedback circuit capable of constraining the average amount of light reaching the wearer's eyes to within ± 3% of any selected lumens level,
   (e) partially-transmissive brow and side-shielding elements,
   (f) polarizing filters on lenses and shielding elements oriented to reduce reflected glare,
   (g) an easy fit over existing prescription lenses and frames,
   (h) total eyewear (frame & lens) weight of 3 ounces or less, and a nose-bearing weight of no more than 1.5 ounces;

   Then: would members of the low vision population be able to wear and adjust (or have a vision specialist adjust) this eyewear to a specific luminance level such that the wearing of the device afforded the wearer significantly improved functional vision as measured by:
   (a) improved acuity, and/or
   (b) increased contrast sensitivity, and/or
   (c) increased field of view, and/or
   (d) better color vision and/or
   (e) improved indoor/outdoor mobility.

2. *If:* that the above specified eyewear does indeed significantly improve the low vision wearer's functional vision;

   Then: what electrical/materials/construction/cosmetic design would best serve the overall needs of this population?

METHODOLOGY

This research is being conducted in six stages:

1) An initial evaluation of available materials/techniques (LC and electrochromic) will be performed.
2) Two prototypes will be designed and constructed (one LC and one electrochromic) employing the most promising of the available materials. To meet the weight requirements and minimize the cost of these initial prototypes, the electronics and batteries will be placed in a small box that will clip to the wearer's belt.
3) The two initial prototypes are being tested by 44 subjects in (a) a battery of clinical vision tests (acuity, contrast sensitivity, field of view and color perception), (b) functional vision (indoor/outdoor reading and recognition tasks, and (c) indoor/outdoor functional mobility trials. The purpose of these will be to informally evaluate the validity of the first research question stated above. Subject observations and comments will also be solicited and recorded.
4) Initial comments and subject observations and comments will be analyzed and sorted by disability categorization and frequency. Final prototype design will be based on these results. Choice of LC or electrochromic technologies will be made, and the specific materials, electronics, sensors, frames, etc., will be made based on user responses.
5) The final prototype will be tested by a larger subject population (104). These will range in age from 55 to 75 years of age and consist of four sub-groups: (a) 26 "normal" subjects, (b) 26 subjects with central vision loss from age-related macular degeneration, (c) 26 subjects with cloudy ocular media and (d) 26 subjects with rod/cone dystrophy.
6) Clinical and functional information will be compiled into specific recommendations for a manufacturable device. This will be published and supplied to potential manufacturers.

Qualitative elements of the above tests will be descriptively presented through measures of central tendency and dispersion. Tabulation and graphic representations will be employed when appropriate. The objective data will be evaluated with multiple paired t-tests or repeated measures ANOVA to identify main effects and interactions of condition by device. Subjective data will form the basis for specific case studies that will complement the objective findings by identifying specific examples of advantages and disadvantages of the eyewear system.

Given the large functional advantage expected (greater than 1 standard deviation), the 44 initial subjects should provide adequate power (>.99) to differentiate between the contributing factors. The 104 subjects employed for the final study will provide more than adequate power (>.99) to differentiate among factors, and will give adequate power (>.85) for differentiating among the four sub-populations.

RESULTS

As of this writing, most of the development of the LC prototype has been completed, and evaluation of electrochromic technology is about to commence. Eight LC materials and technologies were evaluated for optical clarity, dynamic range, spectral distortions and UV and infrared attenuation. Materials/technologies evaluated included two type of nematic molecules, three types of "guest-host" dyes attached to nematic molecules with one or two polarizing filters, a phase change device and a color switching shutter. Of these, the "guest-host" devices were the most promising. Working with a manufacturer, researchers were able to develop a "guest-host" formula and polarizer grating size that yielded a perfect 45% to 2% transmission range with no measurable optical or spectral distortion. Lenses employing this "guest-host" formula have been constructed and integrated into frames.

Light-level sensors have been evaluated and a type of solar cell chosen for use as a light sensor. The solar cell's electronic simplicity, linearity and negative power requirements made it an ideal choice. Finally, a controlling feedback circuit has been developed and tested. The completed device is now functional and is being tested in the laboratory for optical and spectral distortion and proper functioning under a variety of lighting conditions. At this writing the prototype appears to be operating as designed, except under certain lighting conditions. Under these conditions operation becomes unstable, causing some visible flickering. The cause of this is being investigated and investigators expect a solution to be implemented in the near future.

Subject testing is expected to commence in mid April, 1994, and some preliminary results should be available by June, 1994.

DISCUSSION

If the initial hypothesis holds true—that is, that restricting the intensity of light reaching the wearer's eyes to a narrow range will significantly improve (optimize) the wearer's functional vision—then the ultimate result of this work will be an eyewear design for persons with low vision that best suits the needs of this diverse population. The investigators also foresee a mass market appeal for such a device, in which case the purchase price could drop to less than $100 (in 100,000 unit per year quantities). An initial market price between $200 and $250 is predicted by manufacturers (for 10,000 unit per year quantities).

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A LIQUID CRYSTAL ADJUSTABLE POWER LENS MAGNIFIER FOR PERSONS WITH LOW VISION

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ABSTRACT

The purpose of this one-year pilot study is to investigate and develop Liquid Crystal (LC) technology for use as an Adjustable Power Lens (APL) magnifier for persons with low vision. This is a very new concept, as technology has not previously been available for the construction of an APL. Normally, once a lens is formed, its power is fixed because power is a function of the lens material and the curvature of the lens. However, it is now possible to control the power of a lens made of specially formulated LC materials. Once developed, the power of an LC APL could be continuously adjusted by the user to achieve optimal visual ability regardless of reading task or changes in visual function

The specific device outcome of this project is to be a single-lens 4-power clip-on (jeweler's loop) magnifier with at least a 6 diopter adjustment range (2.5x to 5.5x). More importantly, the result will be a more highly developed technology for the design and implementation of APL devices. Ultimately, such a lens may also benefit the much larger population of persons with presbyopia in the form of a single-lens replacement for bi-focals.

BACKGROUND

Statement of the Problem

The condition of low vision exists when a person's best corrected visual acuity (i.e., using traditional glasses or contact lenses) is insufficient for the successful performance of daily living activities and/or the ability to easily read regular-sized print. In America today an estimated 4.3 million have this problem, and the number is growing rapidly with the extended life-expectancies of the aging population [1]. Loss of vision functioning is most prevalent among elderly persons due to the incidence of visual problems related to normal aging and age-related visual pathologies such as cataract, macular degeneration, glaucoma and diabetic retinopathy—the most prevalent of visual impairments. Estimates of the numbers of elderly persons with significant loss of vision function include 13% of non-institutionalized elderly persons. These estimates are significantly higher within older age groups: 16% of those 75 to 84 years old and 27% of those 85 and older are estimated to be visually impaired [2].

Low vision results when an eye disease or injury occurs resulting in permanent damage to the eyes or as the result of some congenital condition which has damaged the eyes. In the presence of low vision, many of the visual tasks a person must complete in the course of their activities of daily living become impossible.

The health care mission of low vision rehabilitation is to facilitate functional independence by maximizing the usefulness of residual vision. The inability to access print is viewed by most as especially debilitating [3], and consequently a common goal of visually impaired individuals seeking rehabilitation is an improved ability to read. Various multi-disciplinary strategies exist, including prescribing optical devices, non-optical devices, electronic devices, and teaching compensatory skills. However, this goal is most often addressed through the use of optical devices that provide magnification of print to a "readable" size. Microscopes (high-powered reading glasses), magnifiers (hand-held and stand models), telescopes arranged for near focus (telemicroscopes) and loupes (variations on jeweler's loupes) are commonly prescribed.

But these reading devices have limitations in that each is useful for only a single task or a narrow range of tasks. The result of this is that the person with low vision must maintain a collection of task-specific devices. This is an expensive solution that increases the complexity and time spent in the performance of ordinary activities and increases the amount of training required for the successful accomplishment of these tasks.

Traditional lenses are of fixed power/focus, meaning that once a given power is ground into a lens, that lens' power cannot be varied. Lens power is determined by manipulating three primary variables: (1) the index of refraction (n) of the lens material (common materials vary from n= 1.5 to 1.7); (2) the base curves ground onto the front and back surface of the lens; and (3) (in stronger lenses) the center thickness of the lens. While this lens property of fixed power is appropriate when used in glasses for correcting common refractive errors (myopia, hyperopia and astigmatism), the use of fixed focus lenses in low vision optical devices limits their range of use.

For example, a hand magnifier of fixed focus/power may work well for print of one size, but for smaller print a separate, stronger magnifier may be required. The same is true for the other optical devices. Furthermore, many ocular diseases which result in low vision are unstable so that gradual decline in vision is expected (e.g., macular degeneration) while others are characterized by periodic fluctuations in vision (e.g., diabetic retinopathy).

The ability to vary the power/focus of a single optical device would be of significant benefit in these cases. With the use of such a system printed material could be accessed consistently regardless of varying print sizes/quality, day-to-day fluctuations in visual function or long-term vision changes. One optical device could maintain its usefulness over time through various stages of decreasing visual function.

Technical Background

Chemists have studied the curiosity of LC materials since the early 1900's and have known that when an electric field is applied to some of these materials their index of refraction changes. However, the idea to form a lens of LC material to achieve adjustable power was not pursued until 1980, when Dr. Ronald Schachar filed a patent for what he called a "Multifocal Ophthalmic Lens" [4]. Dr. Schachar conceived of a "bi-focal" lens constructed of LC materials that would automatically adjust its focal length based on the sight distance of viewed objects. Working with a cooperating LC manufacturer, he was able to devise a first prototype demonstrating the feasibility of the concept. This device was constructed on a glass slide in which LC material was sandwiched between the slide and +1 diopter glass lens (See Figure 1).

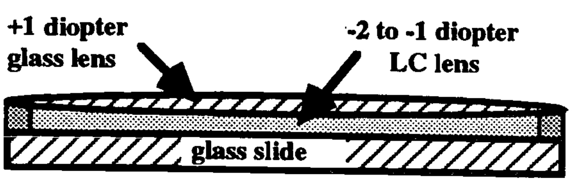

Figure 1. Crossectional Illustration of Schachar Prototype LC APL with an effective -1 to 0 Diopter Range.

As the index of refraction of the LC material in this lens decreases with applied voltage the power of the LC lens increases from -2 diopters to -1 diopter, and the effective power of the LC APL varies from -1 to 0 diopters.

One problem was identified with the construction of this prototype: optical distortion and discoloration were apparent in the thicker areas of the LC material (the sides of the prototype). Further investigation revealed that this was caused by a difficulty in properly aligning the LC molecules when the distance between the containing walls was increased. This difficulty places a limitation on the maximum power (and consequently power range) of an LC lens.

Another concern relates to optical distortion at midrange magnification. Here, maintaining an even electric field throughout the LC material (and thus a consistent index of refraction) is complicated by the variance in spacing between the slide and the lens.

Both of the above concerns are being attacked by the current research.

RESEARCH QUESTIONS

The investigators hypothesize that an LC APL can potentially eliminate the need many persons with low vision have to use multiple optical aids. Given a member of the low vision population, they hypothesize that an LC APL could be devised with a midrange power and power range that would meet all the reading needs of this individual the majority of the time—even as this user's visual function fluctuated or shifted with time. The following key questions to be answered in this pilot study relate to specific optical and human factors issues/conditions that must be evaluated.

Optical Questions

1. Can an LC APL be developed with a dioptric range of 6 or greater?
2. Can an LC APL with a range of 6 diopters be designed to meet the standards of clarity and light transmission required for ophthalmic-quality lenses?

Human Factors Questions

3. Does a panel of 5 experts in vision rehabilitation (having been shown a demonstration of a prototype LC APL) see the potential and practical benefit of the LC APL for the low vision population?
4. Can the LC APL be engineered in a practical and useful form in terms of size, weight, mounting structure, durability and voltage requirements?

A "yes" answer to each of these questions will satisfy the condition that the LC APL has great potential use for persons with low vision.

METHODOLOGY

This research is being conducted in six stages. *First*, the investigators worked with manufacturers of LC material to devise formulations of LC material most likely to exhibit large refractive index changes with applied voltage. The most likely candidates were formulated and enclosed between glass slides for evaluation.

Second, the LC candidates are each being subjected to a series of optical tests including evaluations for refractive variance with applied voltage, optical distortion with applied voltage, evaluations of optical clarity and/or optical diffusion and spectral distortion.

Third, nine LC APL's will be designed and constructed, selecting LC materials and physical designs based on the above results. These will be con-

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structed of varying lens thickness and curvature to test the limits of power and dioptric range.

Fourth, the nine LC APLs will be evaluated for optical clarity, image diffusion, and image distortion versus applied voltage.

Fifth, based on the above results, a clip-on LC APL will be designed and constructed to exhibit the best design possible given existing technology.

Sixth, an expert panel comprised of two low vision experts, two "experienced" low vision consumers and a low vision manufacturer will be asked to evaluate the LC lens prototype. The procedure will consist of a questions and answers session, a demonstration of the prototype and a focus group discussion of the benefits/problems perceived by the panel. Results of the development work and panel conclusions will then be published.

RESULTS

Twelve LC material formulations have been developed and sandwiched between 2" by 2" optical glass slides. The voltage induced refractive variance (Δn) of these samples range from $\Delta n = 0.23$ to 0.29, with an overall index range from $n = 1.5$ to $n = 1.8$. These have been encapsulated in three thicknesses: 50 microns, 100 microns and 200 microns. Initial observation reveals "cloudiness" (scattering) in some samples, but most appear to be optically clear and free of distortion. More rigorous testing will begin in the near future, and detailed results will be available by June, 1994.

DISCUSSION

If the initial hypothesis holds true—that is, that an LC APL with a dioptric range of 6 or greater can be constructed—then the result of this work will be a clip-on "loop" magnifier for persons with low vision that can be adjusted by the user to easily accommodate varying print sizes and vision changes. The cost of this device should be no more than $100, and it should replace collections of fixed-power devices. In addition, if the results are promising, they could lead to the development of other devices, such as zoom lenses (telescopes), and eventually self-focusing "bi-focals" for persons with presbyopia.

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AN INSTRUCTION SEQUENCE FOR ELDERLY PERSONS WITH MACULAR DEGENERATION USING LOW VISION DEVICES

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ABSTRACT

Age-related Macular Degeneration is the most prevalent cause of untreatable visual impairment in this country. Elderly persons with macular degeneration may be prescribed low vision devices (hand-held or stand magnifiers, spectacle mounted magnifiers or telescopes, monoculars or video magnifiers) in order to perform activities of daily living. However, unless the individual is able to develop and maintain the underlying visual skills necessary, the low vision devices may be rejected. This presentation will describe the functional implications of age-related macular degeneration, the development of visual skills, and how the visual skills relate to the successful use of low vision devices.

BACKGROUND

Extrapolating from the Statistical Brief # 36 "Severe Visual Impairment in the United States and in Each State, 1990" (Nelson and Dimitrova, 1993) there were an estimated 6.07 persons per 1000 persons who are visually impaired in the 0-54 age group, while an astonishing 104.1 persons in 1000 persons are visually impaired persons in the 55 + age group. The most dramatic increase is in the "old-old population," there one finds an estimated 210.6 persons per 1000 persons with visual impairment for those 85 years old and older. The most prevalent causes of visual impairment in this country are age-related: macular degeneration, diabetic retinopathy, glaucoma and cataract. Age-related macular degeneration is manifested by changes is the retinal cells of the macula. The macula is the small area of the retina which is responsible for fine detail vision. At present only two known treatments hold promise for the prevention of age-related macular degeneration. Dietary zinc has been associated with a slowing of the loss of acuity after macular degeneration has been manifested in a group of persons with ARMD compared to a control group who took a placebo (Newsome, Swartz, Leone, Elson, Miller, 1988). Protecting the eyes from blue, violet and UV radiation by the use of absorptive lenses has also been suggested to prevent the development of macular degeneration (Goodlaw, 1991). A small proportion of non-exudative macular degeneration advances to the disciform state which involves subretinal neovascularization and the collection of fluid or blood under the retinal pigment epithelium (Bressler, Bressler and Fine, 1988). Laser photocoagulation can stabilize vision loss, however, damaged vision is not restored. Macular degeneration results in permanent loss of central vision. Peripheral vision remains intact if there is no other pathology. Thirty percent of Americans over the age of sixty five have age-related macular degeneration (Miller, 1979). It is the leading cause of new visual impairment, and its incidence increases with age. There is a greater prevalence among women (Ferris, 1982).

STATEMENT OF THE PROBLEM: The end result of age-related macular degeneration is usually a dense scotoma. Symptoms of macular degeneration which has resulted in visual impairment include difficulty with reading, inability to recognize faces, and the distortion or disappearance of the visual field straight ahead. Individuals with this pathology will usually have developed a strongly preferred eccentric viewing position (Cummings, Whittaker, Watson and Budd, 1985), though they may not always be aware that there is a scotoma present.

APPROACH: Instruction in the use of vision and visual skills has been stressed by many authors (Backman and Inde, 1976, Jose, 1983, Faye, 1984, Collins, 1987, Stelmack et al, 1987), but research which substantiates the efficacy of the rehabilitation of vision is sparse. Instruction in the use of devices was considered vital to successful device use in a follow-up study with individuals who had visual loss due to macular degeneration (Nilsson and Nilsson, 1986). Goodrich, Mehr, Quillman, Shaw and Wiley (1977) found that duration and speed of reading increased for users of low vision devices during instruction. Instruction was found to be important in the use of video magnifiers (Goodrich, et al, 1980).

IMPLICATIONS: Two studies of instruction for persons with macular degeneration in the use of vision are notable, however, because of the use of control groups which did not receive rehabilitation instruction. With this research methodology, the efficacy of rehabilitation instruction becomes more pronounced. Nilsson (1990) provided instruction in visual skills, stressing eccentic viewing, and use of low vision devices to a group of individuals with macular degeneration. A control group did not receive rehabilitation instruction, but the optical characteristics of their low vision devices were demonstrated. After one month, the group receiving instruction achieved significantly better results in reading, watching television, and writing letters than the control group. The mean reading speed for the group receiving instruction was 75.5 words per minute, as opposed to 22.6 words per minute for the control group. Watson, Wright and De l'Aune (1992) studied instruction in visual and cognitive strategies for reading with low vision devices for individuals with macular degeneration. Their sample was divided into three groups, an instruction group receiving lessons from a low vision reading specialist, a practice group reading structured practice lessons at home, and a control group who received no intervention. While the instruction group scored highest on a reading evaluation, the practice group also improved. Both groups achieved significantly better results than the control group which received no intervention.

DISCUSSION: Elderly persons with macular degeneration will require specialized instruction in the use of their visual skills in order to maximize success in using vision and low vision devices for tasks that increase independence and quality of life. This presentation will delineate the functional implications of age-related macular degeneration on activities of daily living, background research on the efficacy of instruction in visual skills and the use of low vision devices, and provide the audience with basic guidelines for instruction in the use of visual skills which must be developed by persons with macular degeneration to maximize residual vision. with low vision devices.

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EVALUATION OF A ROBOTIC FINGERSPELLING HAND

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ABSTRACT

A robotic fingerspelling hand has been proposed as an alternative to braille computer peripherals for deaf-blind people whose native language is American Sign Language and whose onset of blindness is after childhood. An evaluation of such a prototype with eight deaf-blind evaluators was conducted. The device conformed to many desirable specifications for such a device, and could fingerspell reasonably clearly for sighted people. However, the intelligibility of the device was not high enough for practical use in tactile reception. The difficulty of producing clear fingerspelling through a robotic hand may have been underestimated in the past, and a very high level of intelligibility would be required in order to rationalize this technology for deaf-blind people.

BACKGROUND

A robotic fingerspelling hand has been proposed as an alternative to braille computer peripherals for deaf-blind people whose native language is American Sign Language and whose onset of blindness is after childhood. Several development efforts have resulted in prototypes (Laenger & Peel, 1978; Beeson, 1981; Gilden & Jaffe, 1986). However, past prototypes could not move fluidly from letter to letter in the manner of normal fingerspelling, and this limitation precluded intelligibility evaluations with the intended users of the device.

In 1992-93, two fingerspelling-hand prototypes based on the design of Dexter II were produced for evaluation. Software was developed to maximize the clarity of the devices' fingerspelling and to incorporate the inter-letter transitions. This paper reports on the user evaluation that concluded this project. The reader is referred to Jaffe et al. (1993) for a description of the hardware design.

METHODS

Evaluators were recruited through local associations and electronic mail networks. Baseline speeds for receptive fingerspelling were first measured by having a skilled signer fingerspell in time with a computerized metronome.
Evaluators signed and/or spoke their responses to each item. Nonsense strings and short sentences were used as stimuli.

When the prototype was ready for evaluation, two sessions of 90 minutes to two hours were conducted with individual evaluators. Sessions combined guided practice, intelligibility tests, and interviews.

At the time of the evaluation, the prototypes had experienced several failures each. Because of the fragility of the devices, evaluators were not invited to subject it to field conditions. Evaluators did not independently operate the prototype.

During both sessions, evaluators' comments while using the hand were recorded. Interviews were conducted in American Sign Language at the end of both sessions.

RESULTS

The sample was composed of eight deaf-blind evaluators. All evaluators of the prototype were theoretically candidates for such a device. Half of the evaluators were proficient in braille, and half were not. Evaluators ranged in age from 19 to 60, with a median age of 38. Seven of the evaluators became deaf before one year of age, and one had onset of hearing loss at age 12. Onset of vision loss was congenital for two evaluators; the remaining six began to experience vision loss at age 10 or later. All reported themselves to be fluent signers, but three of the eight said they were only fair in receptive fingerspelling. (These three had experienced vision loss relatively recently.)

Evaluators' receptive fingerspelling abilities varied widely. Estimated receptive speed, as estimated by the baseline measures using human fingerspellers, ranged from one to seven characters per second for sentence material, and .7 to six characters per second for nonsense strings.

Evaluation of a Robotic Fingerspelling Hand

Table 1 summarizes evaluators' responses to the robotic hand prototype. The data are based on alphabets displayed in random order in both sessions. Evaluators were given as long a time as needed to identify each letter. (Evaluators sometimes offered more than one response, as they were uncertain. Table 1 reflects the evaluators' initial response to each letter.)

Table 1
Intelligibility of Individual Letters

Accuracy Level	Letters
90% or higher	B, C, F, I, L, M, N, R, T, W
80% - 89%	D, K, O, Z
70% - 79%	J, Q, V
60% - 69%	A, G, S, U
Below 60%	E, H, P, X, Y

Note: N = 30 trials for each letter
Eight deaf-blind evaluators (Seven @ four iterations and one @ two iterations)

Overall, accuracy of reception of individual letters did not improve with practice over the two sessions. About half (49%) of 80 simple sentences (ten sentences read by eight evaluators) were received without error. Only two evaluators accurately read more than half of ten simple sentences produced by the robotic hand.

The most successful reader was one who changed her normal hand position for receptive fingerspelling, and addressed the hand from the front. The other evaluators approached the hand by placing their palms on the back of the robotic hand, in the manner used for human sign/fingerspelling reception by many deaf-blind people (not all). These evaluators were not comfortable with changing positions. Deaf-blind people frequently make use of information from the movement of the bones and knuckles in the back of the hand, and these features were absent in the robotic prototype. Evaluators sometimes used both hands to examine the device.

Users found the size and lack of vibration to be acceptable. They were able to use the speed control knob. There were many suggestions for changes in the materials used for the prototype, to make it feel more like a human hand. None of the evaluators felt that the device was intelligible enough for practical use.

DISCUSSION

The prototypes produced for this project were very successful from several perspectives. The prototypes fingerspelled fluidly from letter to letter. Positive qualities of the devices include their small size, portability, quiet operation, negligible vibration, use of standard 110-volt AC power source, use of readily available off-the-shelf components, ease of operation, speed control knob, software designed for easily editing tables, and consistent output of fingerspelling. The prototype won an award from a design magazine in 1993.

The robotic fingerspelling hand performed reasonably well for visual reception of fingerspelled letters. Unfortunately, the results of the evaluation indicate that a device that appears visually to fingerspell acceptably well will not necessarily remain intelligible during tactile reception. For example, the weight of a person's hand on the device can have an effect on hand performance.

Certain improvements in the fingerspelling could be made by software changes. These might include work on some of the collision problems (e.g., transitions to Y). However, thumb collisions are difficult to avoid because the device does not have a feedback mechanism to give precise control of the thumb.

Other suggested improvements would necessitate hardware changes:

- The "down" position of the hand was intended to simulate the wrist flexion used in the letters G, H, P, and Q. The device's movement was imperceptible to many users. The movement should be exaggerated either in length or angle, and perhaps in both; and timing with concurrent hand movements needs to be improved.
- The basic motion of each finger is a continuous contraction. The fingers curl from an upright position into a fist. This makes it impossible to form an accurate K, P, or E.

- The index finger and middle finger do not touch when both are extended, and thus a clear U cannot be made.

In combination, these problems resulted in too many non-standard features in the fingerspelling output, so that the evaluators did not find the output acceptable for real usage.

The prototypes initially experienced failures as a result of breakage of carbon fiber. Some of the problem was alleviated by better packaging for shipping, but carbon fiber should be replaced with some other material if developers continue to work on this type of device. One of the prototypes, after a period of repeated repairs, performed reliably through at least 25 hours of user testing, and is still working well. The other copy was held in reserve in case of failure by the first device, and was not tested in the same way.

CONCLUSIONS

The robotic fingerspelling prototypes produced by PAIRE and ASEL conformed to many of the functional and technical specifications developed under an earlier task of this project. However, the intelligibility of fingerspelling was too low for the device to be useful to intended users--those deaf-blind people who are more fluent in sign than in braille.

The rationale for the fingerspelling hand is that people who are deaf throughout life and who become blind as a result of Usher Syndrome or other causes might learn to receive text through a robotic hand more readily than they would learn braille. This may or may not be true, but cannot be said to have been supported by the results of this project. The deaf-blind people who were the most accurate readers of the robotic prototype were those who were already proficient in braille. To those who were in their earlier stages of deaf-blindness, and learning tactile fingerspelling, the distorted spelling of the hand was a source of frustration and discomfort.

Based on these results, the staff conducting the evaluation conclude that a robotic fingerspelling hand can be rationalized only if the receiver can understand it as accurately and easily as human fingerspelling is understood. Otherwise, it would seem that the deaf person's efforts to learn a new way of receiving information could be more profitably spent on learning braille. Braille's other advantages include the possibility of displaying lines of text (rather than one letter at a time) and the ability to display punctuation, numbers, and word boundaries unambiguously.

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SURVEY OF DEAF-BLIND TECHNOLOGY NEEDS

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ABSTRACT

A Deaf-Blind Technology Needs Questionnaire was designed and administered to deaf-blind individuals throughout the United States. The results of responses from 62 individuals indicate that while some specific new devices are needed, the majority of devices requested already exist, but the consumers are either unaware of them or are unable to obtain them. Some of the requests for new devices may soon enjoy R&D status in our laboratories, and others will be offered to manufacturers of technology for deaf-blind persons.

BACKGROUND

Deaf-blind consumers are small in number but large in need. Sometimes technology designed specifically for either deaf or blind persons is useful to deaf-blind individuals, especially if they have some vision, some hearing, or read braille. Other times, technology specifically designed for those with a dual sensory loss is required.

Developing devices when neither the visual nor auditory channel can be tapped is a formidable challenge. It is therefore especially important to have a clear picture of the needs being addressed before initiating the R&D process.

RESEARCH QUESTIONS

The author sought to determine what deaf-blind persons consider to be their special needs which technology could address. She also wanted to examine two specific problem areas: 1) use of computers, and 2) knowing when to take medication.

METHOD

A Deaf-Blind Technology Needs Questionnaire was developed. The Questionnaire minus introductory queries regarding respondent identification, amount of vision and hearing, and communication methods, appears in Figure 1. The survey was designed to answer some specific questions as well as to provide the respondents with opportunities to be as expansive, comprehensive, and imaginative as possible.

The Questionnaire was administered individually to 62 deaf-blind persons by interpreters from seven different agencies serving deaf-blind clients, plus one private interpreter.

RESULTS

Fifty-eight of the 62 respondents reported using at least minimal technology. Their aids varied in sophistication from canes, large print watches and braille watches, to computers with braille output, TeleBrailles, etc. As indicated in Table I, the list of what respondents would *like* to own also varies greatly in sophistication. (A few of these items are inappropriate responses as they are "nonexistent" devices.)

Table II shows the responses to Question 6, "Do you have any problems which you think a new device could help with? If yes, what are those problems?" Many respondents stated a device rather than a problem. The statements indicate, however, that a large number of problems experienced by deaf-blind people can be solved by existing technology.

Responses to "Use your imagination. Pretend someone could make any kind of new device you would like. Tell me what these new inventions would be" appear in Table III. The primary themes are transportation and communication/information access. Most, but not all, of the devices are indeed not in existence. The development of those dealing with driving are not feasible at this time. Some of the items in both Tables II and III, however, would be ideal R&D projects for an RERC. The vibrotactile signal to indicate end of line on a braille writer, and signal system to indicate when the washer, dryer, and microwave oven have completed their functions, are two examples.

Regarding computer use, only 16 persons responded positively. Eight of these read the screen visually, some with enlargement, and 5 use a braille display. One braille user sometimes uses a sighted reader, and another respondent always uses a sighted reader.

Twenty-six individuals took the opportunity to add other comments at the end of the Questionnaire.

Some asked for specific devices such as "a computer system to enable one to order food or shop via computer," "a braille watch with vibrating alarm (not too large)," and a "more portable [braille] TDD, like the size of a Teletouch. Even one cell would be [useful]." There were also pleas for more devices for deaf-blind consumers and for a means of keeping deaf-blind consumers up to date on the latest technology.

DISCUSSION

The results of this survey indicate that there is much technology in existence which could be of great benefit to deaf-blind persons, but that they are unaware of what is available and/or not able to obtain it. The author makes the following suggestions based on the results of the Questionnaire.

1. The design and development of the several low-technology devices requested should be undertaken by an RERC.
2. The requests for more sophisticated devices should be shared with appropriate manufacturers.
3. When appropriate, deaf-blind persons should be encouraged to learn braille in order to utilize technology designed for blind persons.
4. Professionals who work with deaf-blind people need to be more familiar with what technology is available.
5. Deaf-blind consumers need easier access to what technology is available.
6. Deaf-blind consumers need to be able to obtain the special technology.

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DEAF-BLIND TECHNOLOGY NEEDS QUESTIONNAIRE

4. Do you use any special technology now at home, work, school or any place else? (For example, a TDD, a TeleBraille, a Braille watch, a Braille writer, a Wristcom, a cane, etc.)
   Yes ___ No ___ If yes, name all of them.

   Any other comments regarding special technology which might be helpful for you?

5. Is there any special technology you know of that you would like to own?
   Yes ___ No ___ If yes, name each one.

6. Do you have any problems that you think a new device could help you with?
   Yes ___ No ___ If yes, what are those problems?

7. Use your imagination. Pretend someone could make any kind of new device you would like. Tell me what these new inventions would be.

8. Do you use a computer? Yes _____ No _____
   If yes, how do you access the screen information?

9. Do you take any medicines? Yes _____ No _____

   If yes, a) how do you know when to take them?
   b) would you like a vibrating reminder to let you know when it's time to take your medicine?

10. Please make any other comments you would like regarding special technology which might help you.

Table I. Technology Desired From Current Market

- a large print TDD
- a compact device (this author is uncertain of what is meant here)
- a braille typewriter
- a sewing machine
- a computer with Navigator
- an Optacon
- a Com Tex (the author assumes the respondent meant "Comtek" – an FM listening system)
- a large print computer
- a dot matrix printer
- a computer with braille output
- a microwave oven with braille markings
- a VersaBraille II+
- a vibrating alarm
- a computer
- "a perfected Dexter"
- a smoke and fire detector with a vibrating or fan alarm
- a computer scanner
- a TeleBraille III
- a device "better than Silent Page" to signal when phone rings and fire alarm sounds
- a print-to-braille converter for reading private papers
- a "braille TTY" which also has a large print display
- a telephone with amplification
- a doorbell signaler
- a ringing phone signaler
- an FM listening system
- a talking clock
- a hearing aid
- a TeleBraille
- a Tactile Communicator
- a vibrating sonar cane (the author suspects the respondent meant a "Laser Cane")
- a TDD with printout
- a closed-caption television
- a closed-circuit TV
- a television with a braille display
- a braille clock
- an 80-cell braille display for a computer
- access to television news via braille or mechanical fingerspelling

Table II. Problems Which Might Be Addressed By a Device

- new hearing aid needed
- magnification on sewing machine
- can't hear messages on telephone answering machine
- needs a cordless phone with a volume control
- carpal tunnel syndrome symptoms from extended use of computer keyboard
- vibrotactile signal to indicate end of line on braille writer
- vibrotactile signal to indicate certain computer functions (e.g., loading)
- unable to read computer screen
- need a program to help read (musical?) keyboard
- need portable notetaker with braille display
- improved transportation system
- device to help with street crossings
- improved hearing aid for telephone listening
- computer scanner
- doorbell and phone signaler
- a better hearing aid
- a TeleBraille
- a Tactile Communicator to signal smoke alarms, doorbell, and TDD phone
- a vibrating cane to make going to the store easier
- a CCTV to read maps and small print
- a way to know the weather
- labels on stove and microwave
- a means of traveling independently
- a way to know when the oven timer sounds
- a braille clock with a vibrator
- a Teletouch with keys that do not stick
- an affordable combination TeleBraille and computer which would allow for storing reading material and telephone messages

Table III. Responses to Describing Imaginary Devices

- a compact, moderately priced, portable TeleBraille-type device to enable deaf-blind individuals to communicate with each other
- "comfortable keyboard with built-in mouse and wrist-rester that will eliminate carpal tunnel syndrome problems"
- "something to allow me to have the news currently both national and international" (? sic)
- "a means of being able to get around independently"
- "automobile self-propelled car"
- a pocket-calculator sized device for hearing people to use to communicate with deaf people
- "mechanical robot to lead you around the house . . . programmed to time and task"
- "easy, portable type-to-speech device"
- a device that would allow access to the TV
- a device that would read the newspaper to the user
- a cane,to help with street crossings including information on traffic flow
- braille-captioned television
- braille calculator
- a signal system to indicate when the washer, dryer, and microwave oven have completed their functions
- a tactile money reader
- a robot interpreter to go both from spoken English to signed ASL and vice versa
- a computer and a TV decoder with braille output and tape storage
- a vibrating sound detector (to locate things which fall, to detect knocks, etc., and to detect moving traffic)
- a traffic light signal detector for deaf-blind
- a people locator
- a radar motorcycle
- an "item to be able to drive"
- "radio and TV"
- braille recipes
- braille craft books
- an inexpensive tactile cane
- a vibrating cane
- braille captions
- and an affordable combination TeleBraille and computer which would allow for storing reading material and telephone messages.

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IMPROVED PERCEPTION OF MUSIC, BY VIBRO-TACTILE MEANS, FOR DEAF PEOPLE

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ABSTRACT

Perceiving music through vibro-tactile means is considered. It is seen that pitch perception is so poor that some other means of giving pitch information is necessary. Freed from the need to provide the best possible sensation of pitch, a vibratory system is described which gives good results in terms of providing a sensation of music which gives a useful enhancement to perception, and increased enjoyment of music, for some deaf people.

INTRODUCTION

"Deaf" does not mean "can't hear anything"! The great majority of deaf people can, with suitable technological assistance, perceive music. Musicality is a function of the mind, not the ears (1). There is no indication that people with impaired hearing are inherently any less or more musical than the general population, but technological help is often needed to tap this musicality. The work, of which this is part, makes use of sound processing, the essence of which is the pre-distorting of the sound so as to cancel so far as possible, distortions produced by the dysfunctions of hearing in the individual. This can be carried out to a certain extent with ordinary recorded music (2) and to a greater degree if the music is generated under the control of a computer system (3).

Such sound processing can be supplemented by either a specially created visual representation of the music or by vibro-tactile means. Offering the choice is important because some people are helped, some unaffected, some positively distracted or, in small proportion of cases, actually repulsed by the one or the other.

Many deaf people enjoy dancing, and feeling the music whilst doing so, through vibrations. Vibro-tactile stimulation is thus an obvious thing to consider for enhancing perception of music where a supplement to hearing is appropriate. As a starting point, the approach taken is improving on the use of vibrations which are a mere by-product of sound intended for people with normal hearing. A number of workers have produced vibratory systems intended for deaf people, by fitting loudspeakers into boxes on which a person can sit, stand or lie down, and these have been use quite widely in schools for the deaf. However all of these utilise simply amplified versions of the vibrations produced as mere by-product of ordinary musical sound for hearing people.

Lederman (4) has gone a stage beyond this, especially in the field of vibrating floors. He used a pitch shifter to move the pitch down an octave, or sub-harmonic synthesiser to produce a signal which is an octave below the frequency of the fundamental. This drive signal for the floor gives a substantial improvement. Our own work confirms that the use of a sub-harmonic synthesiser is to be preferred to a pitch shifter, because the fundamental component in the waveform might be weak in a sound whose energy is largely in the harmonics (eg the sound of a double bass).

SEPARATION OF PARTS IN THE MUSIC

The ear-brain is a system with a remarkable ability to separate musical parts in a composite signal. For example it can pick out a moderately prominent oboe part playing against a whole orchestra, which is something no known combination of electronics and computers can do. But the skin of the body has no such advanced processor available to it and when some other part of the body is called on to decipher a vibrating sensation made up of a combination of simultaneous musical parts, it is quite unable to do so.

The separation of the parts is achieved at source. It may be done by having musicians play the two parts simultaneously and record them as separate tracks on tape recorder. However for our experimental work we have chosen to make use of a MIDI module which has two separately assignable audio outputs, the musical notes on each MIDI channel then appear as separate audio signals, which can be amplified and sent to separate vibratory devices. This approach has a number of advantages, especially for experimental work; for example pitch can readily be altered and the shape of the amplitude envelope varied.

Each part is presented through a vibration transducer, on different sides of the body. The gain in perception thereby achieved is very large; but we cannot quantify this. Some deaf people have said that for the first time ever they have been aware of two separate things going on in the music.

PITCH PERCEPTION, AND MUSICAL SCALES

The MIDI module used was a Yamaha TX 81Z. It offers facilities which might be useful to set up one's own musical scales; for vibratory stimuli, it was felt there could be advantages in not retaining the usual equally spaced (on a log scale) notes used for sound in Western art and pop music (to which we are restricting ourselves here). The intention was to determine just noticeable differences (JND) for vibration and to construct a scale for best vibratory perception using these.

Tests were carried out with six deaf students at Doncaster College of the Deaf (Yorkshire, UK). The vibratory sources were 25mm miniature loudspeakers with a mylar top covering, on which a finger tip was lightly placed. Residual hearing was carefully excluded by the use of commercial ear defenders to which small loudspeakers (about 25mm diameter) were attached to the outside. The sound of a waterfall (chosen as being less irritating to the subjects than white noise) was played through these to ensure that the sounds generated by the vibratory test stimulus could not be heard. The results indicated that, under realistic conditions for experiencing music, where each note is experienced as a vibration typically lasting only for a fraction of a second, the smallest interval which could be reliably sensed was a fourth; a fifth being discerned with less effort. A fourth corresponds to a pitch shift of 500 cents or a frequency ratio of 1:1.33. Further that even this extremely course pitch perception performance was only possible over a range of musical notes of about G2 to G4, (where middle C is denoted by C4) corresponding to a frequency range of approximately 100 to 390Hz. Further that this was only possible when there was little variation in amplitude. Beyond these limits, with some individual variation, performance deteriorated. The overall useable range where pitch variation was experienced was about 30 Hz to 600Hz. At much below 30 Hz the sensation begins to be that of individual pulses. Eg at 16 Hz only 4 pulses would be discerned in a note lasting 1/4 of a second.

As a side issue the tests were repeated on six hearing subjects to see if there was any indication that, as popularly believed, deaf people would be more discerning in their perception of vibrations. The greatest care has to be taken to exclude any hearing since with the sense of hearing, pitch changes of a fractions of a semitone can generally be discerned. For these particular subjects and types of vibrations there was no indication of this to tempt us to study the matter more fully.

Accordingly, if a scale is to be constructed to enable pitch perception by vibro-tactile means, the steps in the scale must be no smaller than intervals of a fourth. The largest number of separately pitched notes which we could have in a scale, for reliable differentiation, is thus only 6 or 7.

Musical scales, comparable to those used for sound, based on vibro-tactile perception of pitch are therefore ruled out. Moreover, since no recognition of particular musical intervals such as a fifth or an octave is possible through vibratory means, it could be argued that such musical scales would hardly be meaningful (in the sense of being analogous to scales of sound) in any case.

Since nearly all deaf people have some residual hearing, it therefore makes no sense to vary the tuning of scales from that used for sound, since to do so would require the sounds arrising from the vibratory device to be isolated from those used for residual hearing. Consequently, in our work we use a driving signal for vibro-tactile stimulation which differs only by an integer number of octaves from that used to stimulate hearing.

In consequence we have to accept that pitch perception, other than a general sense of rising and falling, is not capable of being given by a single vibratory source, and that the necessary pitch perception needs to be provided in some other way. Possibilities include; utilising residual hearing, a suitable visual display, a spatial array of vibrations transducers. (A paper on the latter is in preparation.)

In the course of these tests it was also established that different types of musical instrument sounds could be discerned if their amplitude envelope was very different, but apart from intensity changes, waveform changes were not discerned. Hence perhaps 5 different instrument sounds could be used if recognition was to be fairly certain. Further it was indicated that a narrow dynamic range of amplitude would be necessary, probably no more than 10 dB (*cf.* 70dB being not untypical for orchestral sound).

OPTIMAL VIBRO-TACTILE STIMULATION

Freed from the requirement of striving for sufficient pitch perception, there is freedom to design for the best subjective impression of the music. This is an exceedingly important matter; music is a sensation not just information! For example writing down "C, C, G, G, A, A, G - -" is not giving the music of "Twinkle, Twinkle Little Star".

Actually touching a hard vibrating surface, eg with the finger tips, while good for "objective" assessment of the vibration, does not give a sensation which is at all suitable; on the contrary it gives a ticklish sensation, and a number of workers have explained this in terms of the hard surface losing contact with the skin, as the surface moves away from the skin, then making contact again on its return.

Extensive experimentation was carried out with 34 deaf subjects, using different sizes of and types of vibration. A large vibrating surface (37-100mm diameter) was preferred, not in direct contact but coupled through air or a sac of water (or other suitable liquid), and without exception the preferred place was above the lungs. The only variation here was that some preferred it on the back and some on the front of the chest.

Of those subjects who preferred the front of the chest, the preference was described by them as "slight", and in view of the practical difficulty of using large vibrating devices on the front of the chest, it was decided to work only with the back. Music is something which should be experienced in a relaxed way - not like a "medical" thing with devices strapped to the body. A special chair was designed with two long throw 100mm diameter "woofer" type loudspeakers mounted on the chair back on gimbals. When the subject sits back comfortably in this chair, the rim of the loudspeakers is able to conform to the person's back, and an approximation to an air tight seal produced (this is assisted by the wearing of only light clothing). The speakers, driven at frequencies 1 or 2 octaves below the fundamental pitches in the music, compress the air trapped between the cone and the person's back and have been described by subjects, who have become deafened after formerly enjoying music, as being the closest they have experienced to the sensation of musical sound. Most importantly, the sensation is <u>not</u> a vibro-tactile sensation experienced on the skin, but could be described as a "deep body sensation".

ACKNOWLEDGEMENTS

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FUNCTIONAL ASSESSMENT OF VISION UNDER POOR LIGHTING AND CONTRAST: THE SKILL CARD.

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ABSTRACT

A new, simple-to-administer, inexpensive vision test has been devised in order to provide better assessment, early detection and rehabilitation of vision impairment under conditions of poor illumination and contrast. These viewing conditions represent a major problem for the elderly and those with vision impairments due to various retinal and optic nerve diseases. For example, reading menus in dimly lit restaurants, driving at night or at dusk, and many other everyday tasks become difficult for these persons, even though the widely-used clinical vision tests may indicate that their vision is close to normal. The new "SKILL" Card (a low contrast, low luminance acuity card) can detect, quantify, and monitor the types of vision impairments mentioned above by simulating poor viewing conditions under normal office lighting. This provides the eye care professional with a convenient screening test which better correlates with the patient's reported real-world vision problems, and allows more intelligent recommendations for rehabilitative measures to be made.

INTRODUCTION: THE NEED FOR REAL-WORLD VISION PERFORMANCE MEASURES

Most daily tasks involve visual conditions far removed from the customary well-illuminated white test chart with black or gray letters. It is therefore not surprising that people often complain of problems in real-world tasks while presenting clinically with "normal" or near normal acuity. Various laboratory tests have been developed which provide more sophisticated indications of actual visual function. However, despite the superior sensitivity of these laboratory tests, many are not suited to wide-scale clinical use due to their expense, length of the procedure, and the considerable space and special conditions required for use. To obtain clinical acceptance, a test must be rapidly administered, use normal office lighting conditions, require minimal storage and set-up space, and be inexpensive. We have developed a test that meets these criteria.

THE SOLUTION: SKILL CARD DESIGN

The SKILL Card (Figure 1) was conceived as a response to the need for a simple vision test which would give a quantitative measure of retinal function under "real-life" (low contrast and luminance) conditions without special lighting and equipment. A simple near acuity card, designed to be used at 16 inches, is the basis of the test. To simulate low luminance, a 10% reflectance (dark gray) background is used; black letters provide low contrast (16%). On the reverse side of the card is a high contrast, high luminance version of the same test (with different letter ordering). In use, the high contrast side is presented; the card is flipped over and the black-on-gray side is tested. The score is taken as the number of letters of acuity "lost" on the dark versus the light side. The test takes only a couple of minutes.

Because of the high cost of having low contrast test charts printed by conventional methods (mainly due to the difficulty of maintaining consistency with small differences in reflectance of letters and background), a photographic process was developed using a computer-generated background and letter pattern produced on a high-resolution Linotronic-type printer. Approximately 1,000 cards have been produced, for distribution to interested users, with private institutional funding.

The resulting SKILL Card is a truly practical test. It uses familiar, rapid, letter-acuity-based test procedures akin to the familiar Jaeger near acuity card used by most eye care clinicians. It does not take up extra wall or floor space in the office, and does not require special lighting or other equipment. Its estimated production cost is in the $1 to $10 range. Thus the "three A's" criteria -- Acceptability, Availability, and Affordability -- are truly and uniquely met.

RESULTS: PREDICTION OF REAL-WORLD VISUAL PERFORMANCE

Preliminary studies indicate that the SKILL Card does indeed provide a measure of functional visual

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impairment which correlates with difficulties (i.e., handicaps) in real-world tasks. For example, the dependence of reading speed on magnification and window size on a CCTV was studied [1] using the paradigm of Legge, et al. [2] but with maculopathy patients (visual acuities 20/30-20/200). We found an extremely high correlation between reading speed and SKILL Card score (Spearman rank correlation coefficient=0.95, p<.01), pointing to the effectiveness of this test as a predictor of real-world performance.

In a separate study of vision performance and accident rates in older drivers [3, 4], we tested 100 drivers over the age of 55 (not selected for visual deficits) on a battery of vision tests. During the late phases of this project, the SKILL Card became available and 30 subjects were tested. Remarkably, a significant relationship (p<.045) was found between SKILL score and accident rate -- this despite the fact that previous studies with thousands of subjects have generally failed to show any relationship between

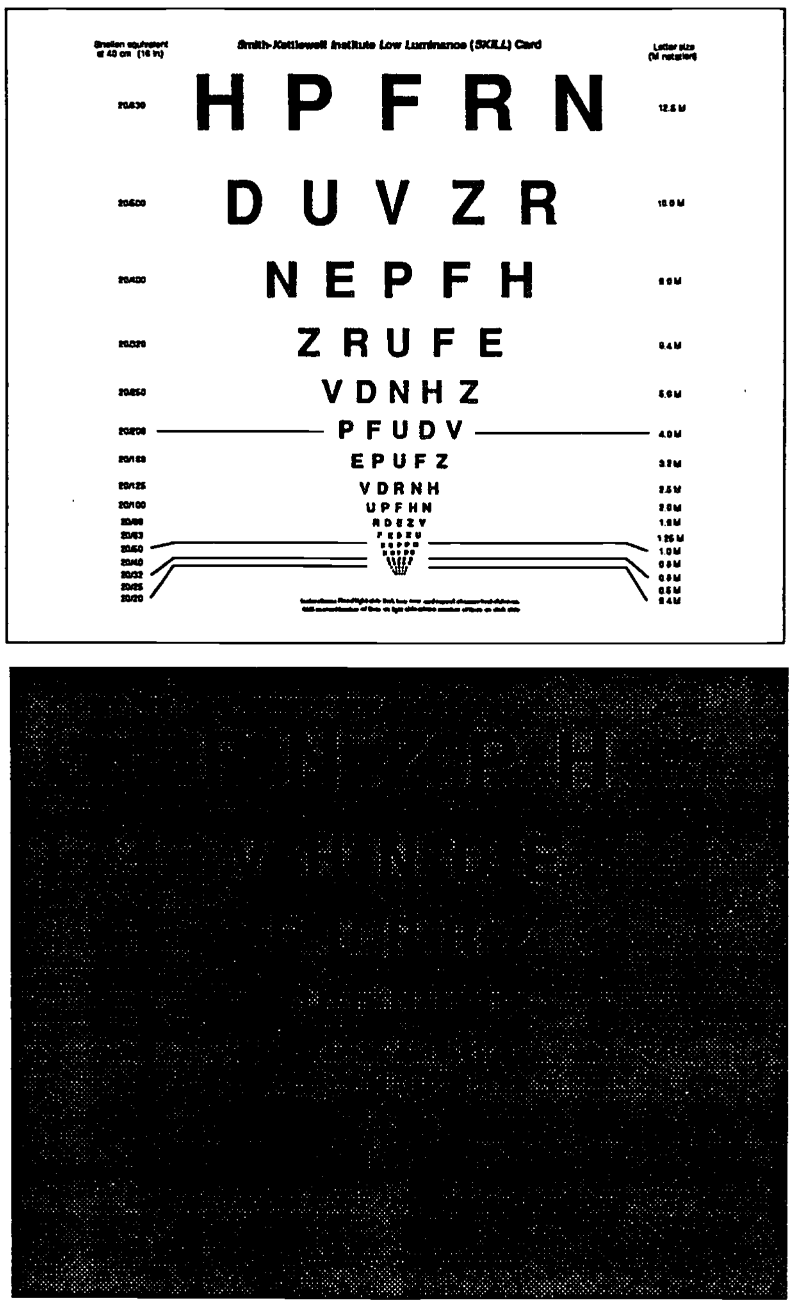

Figure 1

accident rate and visual acuity or other measures of vision. Additional studies to establish the sensitivity, validity and reliability of the new test are under way.

CONCLUSION

The SKILL Card complements existing clinical tests by measuring a different and important aspect of visual impairment (low luminance, low contrast acuity) which correlates with the patient's real-world performance handicaps, while fitting easily into the clinician's acuity-based testing routine. The test requires no expensive equipment, lighting, or wall space, and is very rapid to administer. It shows promise as a screening test which allows better quantification of functional vision impairment, leading to more informed choices for rehabilitative measures such as improvements in lighting and environmental arrangements.

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SIG-09
Wheeled Mobility and Seating

Uniaxial and hydrostatic loading at the core of a gel buttock model

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Abstract. A gel model with an instumented core was designed to simulate a buttock under load. It was loaded on a series of contoured cushions to determine the influence that contour depth, contour shape and cushion stiffness had on core loading. Contouring reduced uniaxial loading and increased hydrostatic loading at the core. The shape of the contour was less influential. Cushions cut to match the actual shape of the indentor were compared with cushions contoured to the measured shape of the model under loading. The actual contoured cushions exerted less uniaxial loading on the core but had similar hyrostatic loading compared with cushions contoured to the measured shape.

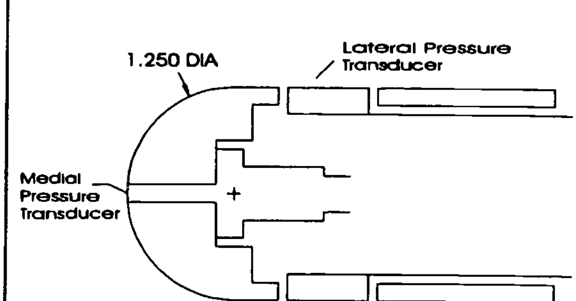
Introduction. Contouring cushion surfaces to reduce interface pressures is becoming more common. Many off-the-shelf cushions incorporate contour aimed at reducing pressures under the ischial tuberosities (i.e., ROHO Enhancer, Isch-Dish, Ultimate, Jay, Wheelnest). In addition, custom contoured cushions are available commercially (Silhouette, Signature 2000, Otto Bock). These systems use some method of measuring buttock shape and then fabricate a cushion based on this measured shape. The effectiveness of the principle behind these systems has been documented (Chung, 1987; Sprigle, 1989). However, the extent to which the effectiveness of custom contoured cushions depends on the 'measured' buttock shape has not yet been determined.

Chow (1974) hypothesized that a cushion cut to match the undeformed shape of the buttocks would minimize tissue distortion and create the optimal sitting surface by maximizing the hydrostatic loading. He used a gel model with an instrumented core to study different support surfaces. He found highest pressures at the tip of the core, but chose to judge surfaces by the amount of hydrostatic loading present. Equivalent Uniaxial Pressure (EUP) was defined as the pressure under minus the pressure on the side of the core (P_{med}-P_{lat}) (Figure). Percent of hydrostatic loading was defined as P_{lat}/P_{med}). However, Chow was unable to test the theory that compliant cushions contoured to the shape of an indentor would provide the optimal pressure distributions.

Objective. This project was designed to address issues not investigated by other model studies. Several variables can be used to compare loading of the buttocks on a cushion. This project used interface pressure, internal pressures and cushion deflection to study the effect of cushion stiffness, contour depth, and contour shape. Stiffness and depth are variables commonly chosen when purchasing a custom contoured cushion, whose shape reflects the measured rather than actual shape of buttocks.

Methods. An axisymmetric model of a buttock was designed based on a section of a hemisphere with an 8.89 cm radius. The model consisted of a solid gel core surrounded by glycerin-based gel (Figure 1). The core (Figure 2) was designed to represent an ischial tuberosity while maintaining axisymmetry and was instrumented to measure pressures at its tip (medial internal pressures) and on two sides of the core (lateral internal pressures).

Figure 1. Cross section schematic of the instrumented core



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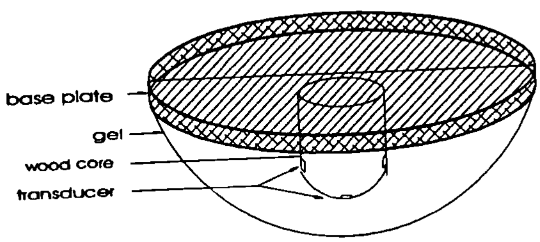
Loading of a gel buttock model

Five pneumatic pressure transducers were attached to the surface of the model, one centered under the core and four at a 5.08 cm radius, to measure interface pressures (medial and lateral external pressures, respectively). The model was loaded on cushions with 21.5 kg to simulate the weight-bearing of one buttock. Cushions were mounted on a contour gage which could measure cushion deflections at 5.08 cm centers.

Figure 2. Schematic of the gel model



Fifteen, 4" thick polyurethane cushions with different characteristics were tested:
3 foam stiffnesses: 45, 55, 70 ILD
3 contour depths: 0 mm (flat), 25 mm, 50 mm
3 contour shapes: 1 '*actual*' & 2 '*measured*'

Measured shapes were obtained by loading the model onto a contour gage configured with foams of different stiffness until a deflection of 50 mm was reached. A cushion based on the *measured* shapes were then fabricated. The *actual* shape was obtained using the equation which defined the shape of the hemisphere of the model. This was the cushion contoured to match the shape of the indentor.

Each cushion was loaded 3 times and seven variables were measured:

- internal & lateral medial pressures
- external medial & lateral pressures
- total vertical deflection of model
- medial and lateral deflection of cushion

This design permitted analysis of the seven dependent variables and 3 independent variables (stiffness, depth, shape), but this abstract will concentrate only on medial and lateral internal pressures with respect to the independent variables.

Results & Discussion. The repeatability of the measures was within 5%. The interaction between foam stiffness and contour shape and the interaction between contour depth and foam stiffness were significant for all 7 variables ($P<.0005$).

Study of the internal core pressures was designed to corroborate Chow's thesis concerning hydrostatic loading. The results clearly indicate that loaded contoured cushions exert less medial and lateral pressures on the core. This is consistent with the clinical studies referenced earlier. However, analysis also raises interesting questions about hydrostatic loading estimates.

The average percent drop in medial pressures from flat cushions to 25 mm contoured cushions was 31%. The average medial pressure drop from 25 mm to 50 mm contoured cushions was only 19%. For EUP, the drops were 43% and 11%, respectively. Furthermore, the percentages of hydrostatic loading (Table 1) within the *actual* contour group do not exhibit large fluctuations.

With respect to shape, comparing the 50 mm cushions in the *actual* and the 2 *measured* shapes, less conclusive results were found. Despite the fact that statistically significant differences existed, the magnitudes of the differences were not large. The *actual* shapes exerted lower medial and lateral pressures on the core, but the percentages of hydrostatic loading was very similar in all 3 shapes.

Conclusion. Analysis of internal core pressures of a gel model show the effectiveness of contouring over different contour depths and cushion stiffnesses. Uniaxial loading was reduced and hydrostatic loading increased. However, because these cushions were fabricated from compliant foam, matching the contour to the exact shape of the indentor did not affect hydrostatic estimations, but did reduce uniaxial loading. Increasing contour depth from 25 to 50 mm did not produce as drastic a change as adding contour to flat cushions. However, given the size of the model, both contours were significantly deep. A 25 mm contour is approximately 50% of the model height and a 50 mm contour nearly envelops the entire model.

These results have clinical significance in that they found that cutting a cushion in the shape of a loaded indentor did not drastically affect pressure characteristics, and while contouring is important, the depth of contour did not appear to increase the amount of hydrostatic loading. More information is needed to affect clinical practice. X-rays were taken of the model as it was loaded onto the 15 cushions to study gel strains. This deformation data will be combined with the pressure information to better define the relationships between internal pressures, interface pressures and tissue distortion.

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Table 1. Loading at the gel model core

		Medial Pressure			Lateral Pressure		
Contour Depth	Contour Shape	45 ILD	55 ILD	70 ILD	45 ILD	55 ILD	70 ILD
0 (flat)	n/a	202.4	190.8	268.9	56.0	58.4	60.8
25 mm	actual	137.2	141.7	168.1	53.2	55.0	62.3
50 mm	actual	110.7	119.9	129.2	38.1	37.2	46.1
50 mm	measured	120.4	139.0	136.5	43.8	48.5	55.3
50 mm	measured	128.2	121.2	145.2	41.3	43.4	54.9
		Equivalent Uniaxial Pressure (EUP): $P_{med}-P_{lat}$			Percentage of hydrostatic loading (P_{lat}/P_{med})		
		45 ILD	55 ILD	70 ILD	45 ILD	55 ILD	70 ILD
0 (flat)	n/a	146.4	132.4	208.2	28%	31%	23%
25 mm	actual	83.9	86.6	98.8	39%	39%	39%
50 mm	actual	72.6	82.6	83.1	34%	31%	36%
50 mm	measured	76.6	90.5	81.2	36%	35%	40%
50 mm	measured	86.8	77.8	90.3	32%	36%	38%

BLOOD LACTATE RESPONSE OF WHEELCHAIR RACERS TO MAXIMAL EXERCISE

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ABSTRACT

People can derive several benefits from wheelchair racing: improved aerobic power, stronger upper extremities, improved psycho-social interaction, and improved mobility. The purpose of this experiment was to determine whether blood lactate accumulation was different for two wheelchair exercise protocols for the same subjects. Eleven male wheelchair road racers with paraplegia participated in this investigation. The order of the tests (e.g., incremental speed, incremental resistance) was randomized. The difference between the concentrations pre and post testing were 8.56±4.424, and 11.67±4.694 mM/l for the resistance and speed tests, respectively. A paired t-test revealed that the pre/post difference for the resistance and speed protocols were significantly different ($p=0.0293$). There are differences in circulatory responses among athletes with paraplegia performing different exercise stress test protocols.

Introduction

Racing wheelchairs are an efficient form of human powered locomotion on roadways. Many people with mobility impairments use wheelchair racing as a means of exercise, and recreation. People can derive several benefits from wheelchair racing: improved aerobic power, stronger upper extremities, improved psycho-social interaction, and improved mobility. Several advances in rehabilitation and wheelchair design have resulted from the efforts of wheelchair athletes, and racing wheelchair designers. Often it is desirable to test the aerobic power of wheelchair users in general or wheelchair athletes specifically. Wheelchair racing may improve aerobic capacity and lactate tolerance permitting one to perform more work. This may have significant implications for longevity, and quality of life.

The maximal metabolic responses of wheelchair users are affected by the exercise protocol employed. Studies have used a variety of different exercise test protocols, including some with wheelchair ergometers, and some with arm crank ergometers. Multiple protocols have been evaluated in the same subjects infrequently. This study was designed the characterize the blood lactate response of a group of male wheelchair racers with paraplegia. This report will focus on a comparison of the lactate responses to two wheelchair exercise protocols.

Research Question The purpose of this experiment was to determine whether blood lactate accumulation was different for two wheelchair exercise protocols for the same subjects.

Methods

Subjects Eleven male wheelchair road racers with paraplegia participated in this investigation. Each subject signed an informed consent document approved by the university committee on activities involving human subjects. All except for one subject who had spina bifida, the subjects were paralyzed due to traumatic spinal cord injury. All subjects participated in regular training regimens.

Each subject was screened by medical history, 12-lead resting electrocardiogram, a battery of clinical pulmonary function tests, and maximal static hand grip strength.

Dynamometer A computer monitored wheelchair dynamometer was used during all exercise tests. The wheelchair dynamometer has been previously described in detail (1).

Protocol Once the subject and his racing wheelchair were secured onto the dynamometer, body temperature was taken orally. Blood pressure was also measured via standard occlusion methods. Resting 5 ml blood samples were taken with a sterile syringe immediately prior to commencement of testing.

The incremental speed test began at 2.23 m/s, with added increments of 0.45 m/s (13 watts) every two minutes until the subject could go no faster. The maximal speed was then maintained until volitional exhaustion. The incremental resistance test was performed at a constant speed of 2.68 m/s. The test began with no resistance on the dynamometer, followed by resistance increases of 10 watts every 90 seconds. The resistance was increased until the subject could no longer maintain the set speed of 2.68 m/s. The subject continued at the last resistance setting where 2.68 m/s could be maintained until volitional exhaustion. The order of the tests (e.g., incremental speed, incremental resistance) was randomized.

Blood pressure and a post test 5 ml blood sample were taken immediately after cessation of exercise. Blood samples were analyzed using an automated system (Yellow Springs Instruments). The system was calibrated prior to analyzing each sample with known standards.

Statistical Analysis The blood lactate responses were compared using two-way analysis of variance (ANOVA) with repeated measures to determine whether responses were significantly different at $\alpha = 0.05$.

Results

Table 1 describes the physical characteristics of the subjects. The blood lactate concentrations pre and post

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exercise testing are presented in Table 2. The difference between the concentrations pre and post testing were 8.56±4.424, and 11.67±4.694 mM/l for the resistance and speed tests, respectively. A paired t-test revealed that the pre/post difference for the resistance and speed protocols were significantly different (p=0.0293).

Table 1. Characterization of the subjects.

Age years	Injury Level	Class	Mass kilogram
28	T5/6	II	71.48
34	T4/5	II	71.10
36	T3/4	II	69.30
41	T5/6	II	72.57
24	T3	II	60.06
29	T9	III	54.20
20	L1/2	IV	65.18
30	T6/7	III	62.62
36	T10/11	IV	74.85
27	T12/L1	IV	62.35
37	T5/6	II	61.77
30.9±5.8			65.95±6.08

The mean pre exercise blood pressures were 125±10/71±7 mmHg for the resistance test, and 123±9/70±7 mmHg for the speed test. Immediately following exercise mean blood pressures were 173±14/18±17 mmHg, and 174±21/18±21 mmHg as measured according to American Heart Association Standards for the resistance and speed tests, respectively. There was no difference (p > .05) between pre or post exercise protocols.

Two-way analysis of variance with repeated measures revealed a significant difference between pre and post blood lactate concentrations for both protocols (p = 0.0001). ANOVA with repeated measures also revealed a significant difference among blood lactate concentrations by resistance and speed protocol (p = 0.003). The speed protocol elicited higher blood lactate concentrations. The interaction between sample time (i.e., pre and post test) and protocol (i.e., resistance and speed) was significant (p = 0.001). This interaction is likely due to one subject having an elevated pre test blood lactate concentration for the speed test. Some subjects may not have fully recovered from the previous test, yielding an elevated blood lactate concentration.

Table 2 Blood lactate concentration in millimoles per liter (mM/l).

RESISTANCE		SPEED	
PRE	POST	PRE	POST
0.9	11.6	2.1	11.7
1.7	4.6	0.8	8.8
1.0	7.5	1.6	4.7
1.6	10.4	1.9	14.4
1.2	12.6	1.5	13.8
1.0	9.5	1.2	14.6
2.55	13.0		17.2
1.4	4.6	1.1	15.2
1.8	12.6	1.4	14.0
2.4	20.0	4.8	26.1
2.3	5.6	1.4	11.2
1.62±.59	10.18±4.57	1.78±1.13	13.79±5.34

Table 3 presents the percent fluid volume shift consequent to peak effort. All volumes are decreases. The mean percent decrease in plasma volume was 12.4±3.62 for the speed tests, and 9.26±3.02 for the resistance tests. The percent decrease in blood volume was 7.14±2.59 for the speed tests, and 5.50±1.61 for the resistance tests. A paired t-test revealed that the percent decrease in plasma volume (p = 0.028) and percent decrease in blood volume (p = 0.035) were significantly different between protocols.

Table 3. Percent decrease in fluid volume shift consequent to peak wheelchair ergometry.

Plasma Volume		Blood Volume	
speed	resistance	speed	resistance
17.6	9.9	12.5	5.6
15.8	8.0	8.3	6.5
9.4	7.7	6.5	5.0
12.1	11.1	5.6	4.9
14.9	9.0	9.0	6.6
13.2	11.7	6.8	4.6
8.5	8.3	8.5	2.1
8.1	9.1	5.5	4.8
17.7	13.9	9.9	8.0
10.0	7.3	6.2	5.0

Table 4 presents the percent hemoglobin (Hb), oxygenated hemoglobin (O_2Hb), carbon monoxide hemoglobin (COHb), oxygen (O_2), and protein (prot) for both increasing resistance and increasing speed peak exercise protocols. The mean corpuscular hemoglobin concentration (Hb • 100)/ hematicrit was determined.

Table 4 Blood concentration changes related to exercise.

Hb gram %	O_2Hb %	COHb %	O_2 Vol %	MCHC	prot gram %
RESISTANCE PROTOCOL					
0.9	45.5	0.0	10.4	0.3	0.6
1.0	22.3	0.0	5.8	1.6	0.6
0.7	27.2	-0.2	5.7	0.4	0.6
1.1	44.5	0.1	9.8	0.2	0.7
0.8	-20.6	-0.9	-3.8	-0.9	0.9
1.0	59.8	0.5	12.9	0.7	0.9
0.7	-2.0	-0.6	0.2	-1.8	1.0
0.3	42.1	0.2	8.4	0.7	1.1
0.7	52.2	0.0	11.0	-0.2	0.9
1.3	36.2	-0.6	9.2	0.2	1.2
0.7	11.8	0.1	2.9	0.4	0.5
SPEED PROTOCOL					
Hb gram %	O_2Hb %	COHb %	O_2 Vol %	MCHC	prot gram %
1.0	27.4	-0.4	7.8	2.2	0.6
1.3	60.4	0.3	13.8	-0.7	1.0
0.9	-9.2	-0.3	-0.1	0.6	0.7
0.7	29.3	-0.2	6.8	-0.8	0.7
0.9	9.5	-0.4	0.0	-1.1	0.9
1.4	26.9	-0.3	6.9	0.5	0.9
0.5	28.1	-0.5	6.1	-1.2	0.7
0.8	6.0	-1.0	1.9	0.8	0.5
1.7	42.9	-0.9	11.2	0.3	1.4
0.9	11.8	0.1	2.9	0.4	0.5

There were no significant (p > .05) differences among any of the circulatory parameters between the two protocols. The mean change in circulatory variables were .84±.266 and 1.01±.357 gram percent hemoglobin content, 29±24.5 and 23.3±19.80 percent oxygenated hemoglobin, -.13±.413 and -.36±.395 percent carbon monoxide hemoglobin, 6.59±5.08, 5.73±4.61 volume percent oxygen content, .143±.888 and .100±.055 mean corpuscular hemoglobin concentration, and .098±.232 and 0.79±.273 gram percent protein for the resistance and speed protocols, respectively.

Discussion

Metabolic measures have been reported to indicate that there are no differences in response by protocol for progressive resistance or speed tests (2). Production of lactate through anaerobic glycolysis in muscle is usually an indication that the oxygen demands of the exercising muscles are outstripping the rate at which oxygen supply mechanisms are delivering oxygen. The blood lactate responses were different for the two protocols. This suggests that respiratory gas and blood samples are required to get an accurate representation of the bodies response to exercise testing. There was also individual variability in the blood lactate response. The difference between the concentrations pre and post testing were 8.56±4.424, and 11.67±4.694 mM/L for the resistance and speed tests, respectively. These values are in agreement with the values reported by Pitteti et al, and within normal ranges for ambulatory people (8-16 mM/L), (3,4,5,6). The speed protocol elicited the higher blood lactate accumulation for the group. This may be because the speed test is similar to the type of training and competing that the athletes employ. This would indicate that they have developed greater lactate tolerance when pushing their wheelchair rapidly. The resistance test may cause greater muscular fatigue, and therefore not be as reliable for measuring central circulatory and metabolic responses.

Total blood volume may be related to endurance fitness. Athletes have a higher blood volume, plasma volume, total hemoglobin content, and erythrocyte volume. Increased blood volume facilitates venous return to the heart, which enhances the Frank-Starling mechanism. Blood and plasma volume decreases were greater for the speed test than for the resistance test. Further indicating differences in circulatory response to the two protocols. Blood volume undergoes dynamic changes during exercise, largely because of increases in hydrostatic pressure. Plasma volume decreases about 10% during prolonged exercise, placing an increasing load on the circulatory system as physical activity continues. The mean percent decrease in plasma volume was 12.4±3.62 for the speed tests, and 9.26±3.02 for the resistance tests. The duration of the speed test (28.3±5.18 min) was longer than that for the resistance test (24.3±1.38 min) which may account for the greater loss in plasma volume.

The common blood parameters measured gave no indication of differences between the two tests. The resting blood pressure measurements were within normal limits, although the pressures measured immediately post exercise were lower than expected for ambulatory subjects who have performed maximal exercise tests.

Conclusion

There are differences in circulatory responses among athletes with paraplegia performing different exercise stress test protocols. Blood lactate, and plasma volume changes were different with the two protocols. This indicates that people with disabilities need to be tested in situations similar to the conditions in which the activity is performed to attain accurate results. Our subjects obtained similar circulatory responses to those expected of ambulatory people.

Acknowledgments

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BIOMECHANICAL ASPECTS ON THE IRV MOBILE HEADREST

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ABSTRACT

A biomechanical evaluation of a headrest with four degrees of freedom from IRV in The Netherlands was made to examine how the forces needed for support and rotation of the head are affected by the axes of the headrest and to give guidelines for adjustments. The analysis was based on mechanical models of a person in a sitting posture connected with a model of the headrest. Gravity, accelerations, geometry of the headrest, the directions of the axes, and the point of intersection for the rotation axes (HRJ) were considered. The analysis showed that the unsymmetrical mass distribution about the sagittal place is a drawback. HRJ should be positioned in the sagittal plane, slightly behind the longitudinal axis of head rotation when the user is sitting in an upright posture. The appropriate position of HRJ in the longitudinal direction depends on the actual strength of the user. The direction of translation should be nearly vertical when the user sits in an upright posture.

BACKGROUND

Persons with severe disabilities may have difficulties in controlling their head position. When the head is stabilized by a headrest forward-backward and sideways, a number of degrees of freedom are still available. The IRV Mobile Headrest (1), allowing four degrees of freedom - one translation and three rotations - is meant as a mobile headrest but can also be used as a control interface.

OBJECTIVES

The objectives of this study were to examine how the forces needed for supporting the head and necessary to apply when the head is rotated by the user are affected by the axes in the headrest and to give guidelines for adapting the headrest to a specific user.

METHOD

Mechanical models of a seated person and the headrest were developed. The models were used as the base for the analysis of how the forces and the torques necessary for maintaining a state of equilibrium are affected by external influences. Finally, the results were applied on the human body and the headrest in a qualitative way.

Models

The conceptual model (Fig. 1) of a person in a sitting posture, based on (2), (3), and (4), consists of the head, the neck (NS), and the backbone (BS) segments. BJ and NJ are ball-and-socket joints. In joint C, located in the dens, only rotation about the longitudinal axis of the head, L, occurs. In joint O, located slightly above the first vertebra, rotations about the sagittal, S, and the transversal, T, axes occur. The suspension groups S1, S2, S3, and S4, consisting of springs, viscous dampers, and dry friction elements, model factors which influence the mobility and stability, both internal and external. Perpendicular to the sagittal plane, defined by the normal T, corresponding suspension groups are acting. Torsional resistance in C and resistances about S and T in joint O were neglected. The distances dOS and dOL describe the relation between C and O. dmL and dmS describe the relation between O and the center of mass. m is the mass of the head.

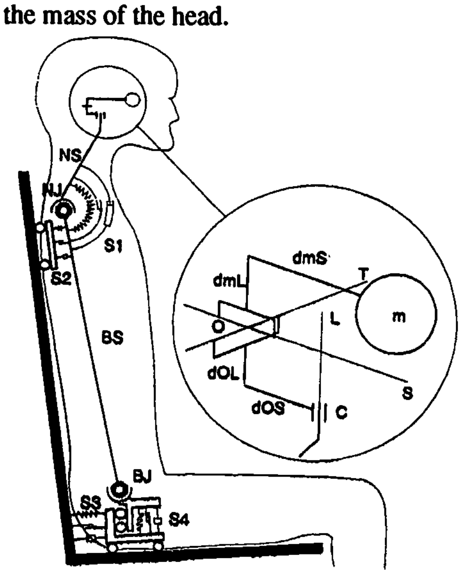

Fig. 1 Conceptual model of a sitting person

A simplified model was also used in the analysis (Fig. 2). The main simplification is the assumption that the longitudinal axis does not change direction due to the movements of the neck segment. Since the studies only concern static equilibrium, the damping and frictional elements are neglected. The influences on C by BS, NS,

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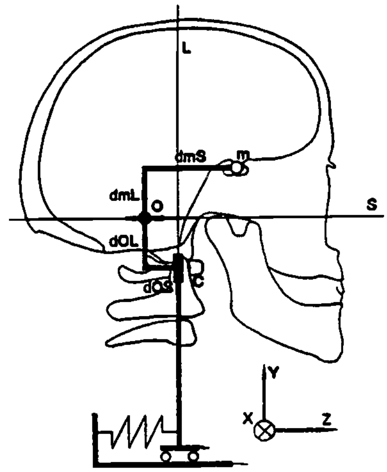

Fig. 2 A model of the head and neck segments

and the suspension groups are described by the springs, one acting in Z-direction and one in X-direction (not shown in the figure).

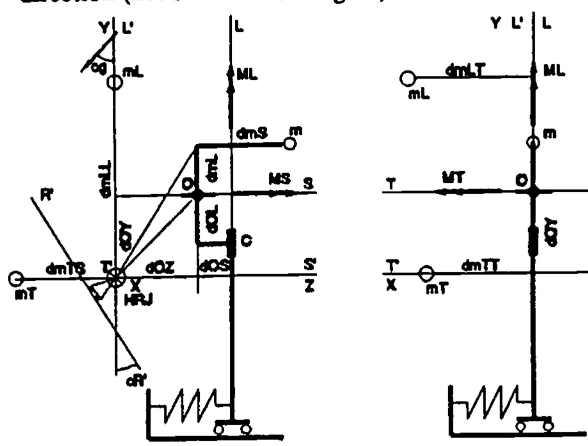

Fig. 3 A model of the headrest connected with the head segment of the conceptual model.

The combined head and headrest model in Fig. 3 consists of the model in Fig. 2 connected with a model of the headrest and is based on the assumption that the cap (the part of the headrest which is attached to the head) is fixed to the head.

The S', T', and L' axes describe the axes of rotation in the headrest, in sagittal, transversal, and longitudinal directions respectively, and are assumed to intersect each other in the headrest joint, HRJ. The distances dOX, dOY, and dOZ describe the relation between HRJ and O. The origin of the coordinates X, Y, and Z is fixed in space but the coordinate system rotates with the angle cg between Y and the field of gravity. HRJ moves along the linear redundant axis, R'. cR' is the angle between R' and Y. bS, bT, and bL are the angles of rotation about S', T', and L' respectively. bL influences the direction of S' and T' and bT influences the direction of S' The bar between S' and T' in the headrest is modelled by the mass mT, located at the distances dmTS and dmTT from HRJ and is affected by bT and bL. The mass mL, located at the distances dmLT and dmLL from HRJ, describes the bar between T' and L'. bL affects the position of mL. The masses from the bars may produce external torques about the axes. The internal torques MS, MT, and ML are applied to the model in order to maintain a state of equilibrium. They are assumed to describe, in a qualitative way, the torques which must be applied by the user.

<u>Analysis</u>
Factors considered in the analysis were the field of gravity, accelerations, the redundant axis, the cap, the direction of the axes of rotation in the headrest and the position of HRJ. A mathematical description of the model in Fig. 3 was used in a calculation program with graphic outputs.

RESULTS AND DISCUSSION

<u>The field of gravity</u>
In order to reduce the forces in the neck region and between the head and the cap when the backrest is inclined, it is necessary to move the headrest relative to the backrest. The external torque about the sagittal axis is almost zero due to gravity which is satisfactory. The external torque about the transverse axis tends to rotate the head backwards. External torque about the longitudinal axis occurs when the directions of the longitudinal axis and the field of gravity do not coincide. This reduces the possibility to relax when the backrest is inclined, since the user needs to apply a counterbalancing torque in order to avoid unvoluntary rotation of the head. The magnitudes and directions of the external torques due to the field of gravity can be changed by adding masses and changing the positions of the centers of mass in the headrest bars. If the user has unsymmetrical strength, it is possible to make the external torques unsymmetrical about the desired axis.

<u>Accelerations</u>
Vertical acceleration causes movement of the body of the user which must be allowed by the headrest in order to reduce the forces between the user and the headrest. Movements are allowed by the linear redundant axis. In order to reduce the forces, torques and movements due to external and voluntary accelerations, the masses, dimensions, and distances between the centers of mass and the axes of rotation must be minimized. Symmetrical mass distribution of the rotating parts of the

headrest about the sagittal plane is desired. Movements of the user's body in sagittal and transverse direction and injurious forces in the neck region due to accelerations can be avoided partly by using for instance an anatomically correct seat and backrest contour, belts, side supports, and adjusted foot supports. If the headrest is used for wheelchair controlling purposes, the undesired changes in head position due to external accelerations must be taken into account in the control electronics or program. The longitudinal axis of rotation, in relation to the combined center of mass of both the head and the parts of the headrest which rotate about the longitudinal axis, is important if this degree of freedom is used for steering. From a point of view concerning the strength needed for steering, the longitudinal axis has to intersect the combined center of mass. From another point of view concerning safety considerations, the combined center of mass must not be positioned behind the longitudinal axis if the user steers towards the direction he looks at, as that will cause torque which tends to increase the manoeuver.

The linear redundant axis

The forces in the spinal column, the head, and the interface between the head and the headrest, due to the variation of length of the spine and the thickness of the cushions, can be reduced if the spinal column is allowed to change its length. This is permitted by the redundant axis. The relatively large changes in distance between the seat frame and the head which occur when the user inclines the backrest can be compensated for by another mechanism than the device used for the small and frequently occurring alterations, in order to keep the mobile parts of the headrest as light as possible. The longitudinal forces are reduced in the spinal column if the angle between the longitudinal axis of the head and the linear redundant axis is close to zero. The movement of the headrest insagittal direction by rotating the redundant axis is therefore good.

Directions of the axes of rotation in the headrest

As long as the axes of rotation in the headrest intersect in one point, the head can move in the same way irrespective of the directions of the axes. In order to reduce the effects from the external torques due to the field of gravity, the direction of the longitudinal axis in the headrest would coincide with the direction of the field of gravity and the direction of the transverse axis would be a normal to the sagittal plane of the user. In order to facilitate the programming of the controlling computers, the axes of rotation in the headrest would correspond to the axes of rotation in the head. In order to avoid unnatural movement when using the headrest for controlling purposes, it is important that the headrest is adjusted in the way the control program assumes.

Position of HRJ

HRJ must be located in the sagittal plane, dOX=0, if it is desirable to avoid the application of neck muscle torque when the angles of rotation are zero. If a user has unsymmetrical strength about the longitudinal axis, dOX can be chosen in a way that makes the use of the headrest easier. In order to counterbalance the external torque caused by the headrest itself, the distance dOX can be changed. If the distance in longitudinal direction between the modelled joint and HRJ is increased, the forces in the joints of the neck in resting position are reduced, but the movements of the neck in transverse and sagittal directions are increased, which may cause increased forces when a certain rotation is performed. The distance is therefore user dependent. In order to reduce the movements along the redundant axis, the distance between the transverse axes in the head and in the headrest has to be close to zero. In order to avoid instability tendencies when for instance the backrest is inclined, the distance between the longitudinal axes in the head and in the headrest must be changeable. In an upright posture, stability about the longitudinal axis is maintained if HRJ is slightly behind the longitudinal axis of the head.

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SURFACE ASSESSMENT DEVICES FOR ACCESSIBILITY

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ABSTRACT

Physical characteristics of a surface affect the level of accessibility of the surface to wheelchair users and others with mobility limitations. The objectives of this research project were to evaluate and compare existing and prototype surface assessment devices to determine which device(s) quantitatively measure the characteristics of a surface that affect its degree of accessibility. Four test surfaces were assessed using three existing and three prototype devices. The rolling resistance of a wheelchair was measured and used as an indicator of the degree of accessibility of the surface. Evaluation of the results revealed that existing surface assessment devices are inadequate for this application. The prototype tire penetrometer surface assessment device produced the most favorable results. With further refinement, this device could potentially be used to objectively assess both indoor and outdoor surfaces for accessibility.

BACKGROUND

The physical characteristics of a surface that affect its level of accessibility have been identified as: resistance to penetration, sheer strength, slipperiness, water content, and presence of obstacles (1). Past research has demonstrated that carpeting imposes a burden upon wheelchair users when compared to a concrete surface in terms of the amount of metabolic energy required to travel a given distance (2). It is also known that the rolling resistance of wheelchair tires on carpet is three times that on concrete (3). Measuring surfaces in terms of metabolic energy expenditure or wheelchair rolling resistance would be difficult to accomplish in outdoor environments. Since rolling resistance does not vary significantly with speed, an indirect method would be the easiest way to measure rolling resistance on various surfaces (3). Therefore, a surface assessment device that produces measurements that correlate with wheelchair rolling resistance could be used to assess surfaces.

STATEMENT OF THE PROBLEM

A portable surface assessment device that measures the degree of accessibility of a wide range of surfaces does not exist. Existing surfaces assessment devices, including the cone penetrometer, pocket penetrometer, Turf-Tec penetrometer and stimpmeter, do not produce reliable results on a wide range of indoor and outdoor surfaces. In addition, the measurements obtained with these devices have not been correlated to the accessibility of the surface to wheelchairs.

RATIONALE

The Americans with Disabilities Act Accessibility Guidelines (ADAAG) do not include specific requirements for the physical characteristics of ground surfaces that relate to its accessibility to wheelchair users. The guidelines require that ground and floor surfaces be stable, firm, and slip-resistant, and that the maximum carpet pile thickness be 0.5 inch. The guidelines do not include specifications for the penetrability of the surface. Although there are no requirements for carpet in the present regulations of the California Architectural Barrier Laws (4), it was recognized that regulations for face weight, pile height, construction and padding should exist to insure nondiscriminatory access. In order to determine the specifications for these regulations, a means of objectively measuring surface characteristics needs to be developed.

An appropriate surface assessment device would provide wheelchair users and other persons that have mobility limitations the information needed to determine the accessibility of an environment. A device may also facilitate the development of guidelines or standards for accessible ground surfaces.

DESIGN AND DEVELOPMENT

Three prototype surface assessment devices were designed and fabricated. Each device pressed into the surface during the measurement process similar to what occurs as a wheelchair travels across a surface. The design parameters were varied and initial testing of each device was conducted to evaluate the feasibility of the design concept and to determine the optimal design parameters.

The *modified stimpmeters* consisted of weighted objects and a 24 inch ramp inclined 15 degrees above the horizontal. Each object was released down the incline and onto the test surface. The distance the object traveled on the surface was measured. Seven different objects were evaluated. Three cylindrical objects, 3-5 lb. in weight, had different treads: ridged, tire and waffle. Four dumbbells ranging from 5-20 lb. were also used.

The *tire penetrometer* was constructed from a section of a solid wheelchair caster. The caster was pressed into the surface with a vertical force of 33 lb. and the amount of displacement of the device into the test surface was measured to the nearest 0.01 in with a dial caliper.

The *rolling penetrometers* consisted of weighted carts that were pulled across the test surface. One cart had 5 inch casters and the other had 8 inch casters. The force required to pull the cart at a constant rate was measured.

A *system for measuring wheelchair rolling resistance* was also developed. The system consisted of a loaded, standard depot wheelchair, an adjustable speed motor to pull the wheelchair, and two load cells interfaced to a computer data acquisition system. The force required to pull the loaded wheelchair at a constant speed across the surface was measured. Data was collected at a frequency of 10 Hz.

EVALUATION

Method

Three existing surface assessment devices and all variations of the three prototype devices were used to assess four different test surfaces (Table 1). The test surfaces included: 1) a hard level surface with a high coefficient of friction, 2) carpet with 3/4" level cut pile with padding, 3) #1 plaster sand[1], and 4) 3/8" pea gravel. Three measurements were taken on each test surface and the average was calculated. The wheelchair rolling resistance was also measured on each surface. Correlation coefficients were then calculated for each device.

Table 1. Surface Assessment Devices Evaluated.

Existing Devices	**Variation**	**Abbr.**
Pocket penetrometer		PP
Stimpmeter		SM
Turf-Tec penetrometer		TTP
Prototype Devices	**Variation**	**Abbr.**
Modified stimpmeters	ridged	SM-R
	tire	SM-T
	waffle	SM-W
Modified stimpmeters	5 lb. dumbbell	SM-5
	10 lb.	SM-10
	15 lb.	SM-15
	20 lb.	SM-20
Tire penetrometer		TP
Rolling penetrometer	5" caster cart	RP-5
	8" caster cart	RP-8

Results

For all stimpmeters and the Turf-Tec penetrometer, measurements decreased as the penetrability of the surface increased (Figure 1). Conversely, for the pocket penetrometer, tire penetrometer and rolling penetrometers, a softer or less firm surface produced higher readings (Figures 2,3).

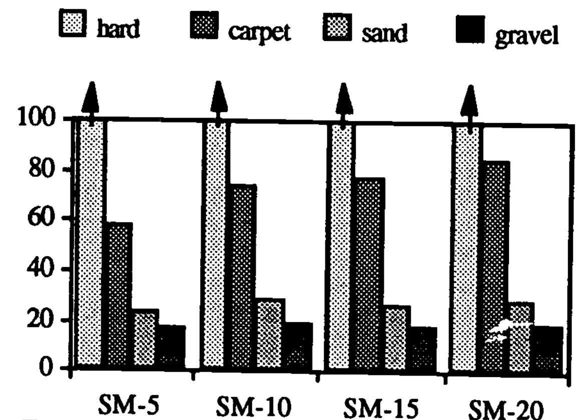

Figure 1. Modified Stimpmeter: Distances (in) Traveled by Dumbbells

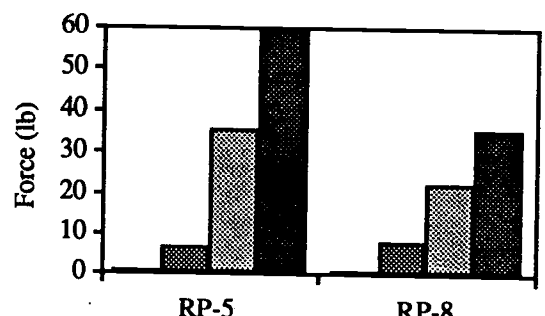

Figure 2. Rolling Penetrometer: Forces (lb) Required to Pull 5 and 8 in. Caster Carts.

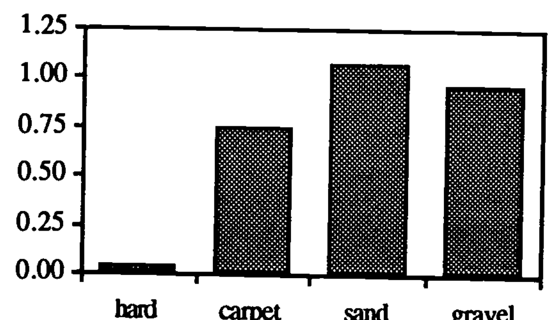

Figure 3. Tire Penetrometer: Amount of Displacement (in).

The average readings recorded with each device were correlated with the wheelchair rolling resistance measured (Table 2). Nine of the 13 devices did not produce reliable results on the hard level surface. The force required to pull the 5 in caster cart across the pea gravel exceeded the limits of the force transducer used. If the correlation coefficient included the measurement on this surface, it would be less than 1.00. The dumbbell stimpmeters produced the best correlation with the wheelchair rolling resistance measured on carpet, sand and gravel.

[1] KSG #1 plaster sand: 84% passed through #30 sieve; and 37% passed through #50 sieve.

Table 2. Correlation Between Measurements Obtained with Devices and Wheelchair Rolling Resistance

Existing Device	Correlation Coefficient
PP	0.92*
SM	-0.74*
TTP	-1.00

Prototype Device	Correlation Coefficient
SM-R	-0.79*
SM-T	-0.99*
SM-W	-0.90*
SM-5	-0.97*
SM-10	-0.96*
SM-15	-0.97*
SM-20	-0.97*
TP	0.83
RP-5	1.00 ^
RP-8	0.90

* Does not include hard level surface data.
^ Does not include pea gravel data.

DISCUSSION

All of the existing devices that were evaluated exhibited problems or limitations in the range of surfaces it could assess. The pocket penetrometer and stimpmeter exceeded their range of measurement on the hard level surface. The Turf-Tec penetrometer could not differentiate between the sand and the pea gravel.

The hard level surface was difficult to assess with all the modified stimpmeters since any surface irregularities or slight changes in slope significantly affected the distance the object traveled. The measurements made on the other surfaces were repeatable and showed a high correlation with the wheelchair rolling resistance. Overall, the dumbbells performed better than the other objects tested. When the dumbbells were rolled over the surface, the profile created in the surface was similar to that left by a wheelchair. This device was portable and easy to use.

The tire penetrometer and rolling penetrometers were the only devices that were capable of assessing all four test surfaces. Although the rolling penetrometers produced favorable results, the weights of the caster carts make this device difficult to transport.

The tire penetrometer had a correlation coefficient of only 0.83, but this device was capable of measuring a wide range of surface types, and it was portable and easy to use. For these reasons, the tire penetrometer produced the most favorable results.

Future work includes refinement of the design of the tire penetrometer and evaluation of the repeatability of the measurements obtained with this device. Future research should include measuring the metabolic energy requirements for traveling across various surfaces in a controlled environment. This information will assist in the final calibration of the surface assessment device. The development of a device that is reliable over a wide range of surfaces will allow wheelchair users and others with mobility limitations to determine the degree of accessibility of both indoor and outdoor environments.

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ASSESSMENT OF OUTDOOR ENVIRONMENTS FOR ACCESSIBILITY

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ABSTRACT

Existing definitions for accessible routes and trail grading systems do not provide persons that have mobility or visual limitations the objective information needed to determine if an environment can be negotiated independently, with assistance, or not at all. The objectives of this research project were to develop a quantitative system for assessing outdoor environments for accessibility and to evaluate the reliability of the methodology. Four objective measurements were taken at regular intervals: grade, cross slope, width, and surface type. Using the assessment procedure developed, 12 trails were assessed, and the reliability of the methodology was verified during re-assessment of two trails. This assessment procedure provides more accurate and objective information regarding the accessibility of the environment to wheelchair users.

BACKGROUND

The Americans with Disabilities Act Accessibility Guidelines (ADAAG) define specific requirements for ramps and accessible routes to and inside of buildings (1). These regulations were never intended to apply to outdoor environments. ADAAG states that a ramp must meet the following criteria: maximum slope of one inch of rise for every twelve inches of length, minimum four feet wide, maximum two percent side slope, a level landing every thirty feet, railing, etc. It is not only impractical to build outdoor environments to such standards, but it is also not always desirable.

STATEMENT OF THE PROBLEM

ADAAG requirements for indoor environments and access routes cannot be applied to outdoor environments. The guidelines for assessing highly developed environments lack specific measurement protocols and do not reflect the conditions actually encountered by wheelchair users. Running slope is often measured over very long distances which can result in an average grade that complies with ADAAG and grades over shorter distances that fail to meet the requirements. Outdoor environments, such as city sidewalks, can be extremely inconsistent in grade, cross slope, width, and surface type. Obstacles not found indoors, such as rocks, ruts, and roots, are frequently encountered in the outdoor environment and existing measurement procedures do not take this into account.

RATIONALE

The development of an outdoor assessment procedure would provide persons with mobility limitations meaningful information about the accessibility of the environment. It would also facilitate the development of guidelines or standards for outdoor environments. The Architectural and Transportation Barriers Compliance Board (ATBCB or Access Board) is in the process of developing design guidelines for outdoor recreation areas. This includes recommendations for running slope, maximum grade, cross slope, width, and surface characteristics for outdoor environments.

DESIGN

Five surface characteristics that affect a wheelchair user's accessibility have been identified as: grade, cross slope, width, surface type and presence of obstacles (2). The assessment procedure involved measuring the first four characteristics at regular intervals and documenting the location and size of any obstacles encountered. Average grade was measured with a clinometer. Maximum grade and cross slope measurements were taken across short distances which correspond to the grade and cross slope angles experienced by a wheelchair. The average trail width was computed by weighting each width measurement by the distance between the measurement stations. Surface type was evaluated subjectively and classified into one of four categories: hard, medium, soft, or very soft. A surface assessment device is currently under development and will be incorporated into future assessments (3). The development and evaluation of only the grade and cross slope measurements will be discussed.

DEVELOPMENT

The grade and cross slope inclinometers were used to measure maximum grades and cross slopes across a distance equivalent to the length of the instrument. If small rocks, ruts or roots were present, one end of the instrument was placed on top of the protuberance to measure the angle. As the length of the inclinometer was increased, this angle decreased. The angle measured should be similar to the angle experienced by a wheelchair as it traverses across the surface. Therefore, the length of the measurement tool should reflect the wheel base dimensions of an average wheelchair.

In order to determine the average wheel base length and width, data was received from three sources: Everest & Jennings, Invacare, and the Department of Veterans Affairs in Baltimore. A total of 36 wheelchairs were measured. The average wheelchair wheel base length was 16.8 inches and the average wheel base width was 21.8 inches.

A small experiment was conducted to analyze how the length of the grade and cross slope inclinometers affect the calculated averages. The grades of two short trails were assessed twice by different individuals using tools of three different lengths: 16, 22 and 48 inches. As expected, the average grade decreased as the length of the tool increased. As the length of the tool increased from 16 to 48 in., there was an average decrease of 4.9% in the measurement values. The difference between the average grades measured with the 16 and 22 inch tools was insignificant (0.5%).

Based upon the average wheelchair wheel base dimensions and the results of the tool length experiment, it was decided that the lengths of both the grade and cross slope inclinometers should be 24 inches. This corresponds to the length of commercially available tools.

Table 1. Angle Conversion Table.

% Grade	Degree	Rise:Run
2.0	1.1	1:50
3.5	2.0	1:28.6
5.0	2.9	1:20
8.3	4.8	1:12
10.0	5.7	1:10
12.5	7.1	1:8

Example: 1.1 deg is equal to 2% and 1:50

EVALUATION

Ten outdoor hiking trails were assessed using the developed procedure (Table 2). While the majority of the average grades were less than 8.3%, all maximum grades measured with the grade inclinometer exceeded the current ADAAG requirements. Six of the trails assessed had average cross slopes ranging from 5-10%. Only one had an average cross slope of 2%.

Two trails, Fairy Falls and Ice Lake, were assessed in 1991 and then again in 1993 with a different assessment team using two assessment procedures (Table 3). Comparison of Fairy Falls and Ice Lake trail data, assessed in 1991 by one assessment team and then in 1993 by a different assessment team, revealed the following:

1. Average grade readings were very consistent (±0.3%) for 1991 and 1993.
2. Average cross slope measurements were very consistent (±0.2%) for 1991 and 1993 on Ice Lake. On Fairy Falls, the average cross slope increased due to the narrow trail width and the decrease in the length of the measurement tool. In 1993, the smaller measurement intervals used during sections of the trail with steeper cross slopes skewed the average reading. This skewing did not occur when the measurements were weighted by the distance between the stations.
3. Maximum cross slope readings decreased for both trails due to the decrease in the length of the measurement tool. The maximum cross slope readings over a shorter distance more accurately reflect what a wheelchair experiences.

The consistency of the average grade measurements recorded in 1991 and 1993 demonstrated that the procedure is repeatable, even between different assessment teams. By decreasing the length of the grade and cross slope inclinometer to correspond with the wheel base length and width of the standard wheelchair, the accuracy of the these readings was increased. By computing the weighted averages for cross slope and trail width measurements taken at the stations, the accuracy of this information was improved.

Table 2. Results of 10 Trail Assessments (%).

Trail	Ave Grade	Max Grade	Ave Cross Slope	Max Cross Slope
Beehive	10	47	9	34
Boiling River	4	62	7	32
Fairy Falls	3	40	10	25
Grotto Falls	4	19	2	12
Ice Lake	3	14	6	9
Kersey Lake	5	70	11	32
Mystic Falls	6	62	9	36
Palisades Falls	10	32	3	14
Pine Crk Falls	8	75	16	47
Wraith Falls	6	42	6	18

Table 3. Fairy Falls and Ice Lake Trail Data (%)

Trail & Date Assessed	Ave Grade	Max Grade	Ave Cross Slope	Max Cross Slope
Ice Lake '91	3.8	-	5.8	15.8
Ice Lake '93	3.5	14.1	5.6	8.7
Ice Lake '93*	3.5	14.1	2.6	8.7
Fairy Falls '91	3.0	-	5.3	38.4
Fairy Falls '93	3.1	40.4	10.5	24.9
Fairy Falls '93*	3.1	40.4	4.6	24.9

* Cross slope measurements were taken at each measurement station and weighted averages were calculated.

DISCUSSION

Based upon the results of this research project, the following conclusions were made:

1. Grade and cross slope should be measured with a 24-inch inclinometer. Measurements made with this instrument reflect the angles a wheelchair experiences as it travels across the surface. This assessment procedure takes into account the variations in the surface that occur over short distances. These surface irregularities, often found in outdoor environments, affect the mobility of a wheelchair user and others with mobility or visual impairments.

2. The assessment procedure that was developed produced repeatable results that provide relevant information to wheelchair users and others with mobility limitations. This assessment procedure would give reliable results in both indoor and outdoor environments.

3. Existing ADAAG requirements should not be applied to outdoor environments. None of the ten trails assessed complied with these requirements. Extensive, costly modifications would need to be made in order for any of the trails to meet the indoor accessibility guidelines. Using existing techniques, it is not feasible to construct outdoor access routes with cross slopes less than 2% (1.1 deg). Subject testing could be performed to determine the maximum cross slope that should be allowed.

4. Design guidelines for access to outdoor environments need to be developed and supplemented with research. The data collected during Phase I of this research project has assisted in the establishment of preliminary design recommend- ations for easy, moderate, difficult, and most difficult trails within USDA forests (Tables 4, 5) (4). The Recreation Access Advisory Board will use these design guidelines as a starting point for developing preliminary recommendations for outdoor recreation access routes and recreation trails in urban/rural, roaded natural, semi-primitive and primitive settings.

Future Research

During trail assessments it was noted that excessive cross slope alone was not a significant inhibitor of access to the environment. Future research should focus on the effects of various combinations of grades and cross slopes on physiological variables or perceived ratings of exertion.

Table 4. USDA Forest Service Design Guide: Design Guidelines for Outdoor Recreation Access Routes

	Urban/ Rural	Roaded Natural	Semi-Primitive
	Easy	Moderate	Difficult
max running slope	5 %	5 %	5 %
min clear width	48 in	36 in	36 in
max grade	10 %	10 %	10 %
max grade run	50 ft	50 ft	50 ft
max cross slope	3.5 %	3.5 %	3.5 %
obstacles	1/2 in	1/2 in	1 in

Table 5. USDA Forest Service Design Guide: Design Guidelines for Accessible Recreation Trails

	Urban/ Rural	Roaded Natural	Semi-Primitive
	Easy	Moderate	Difficult
max running slope	5 %	8.3 %	12.5 %
min clear width	48 in	36 in	28 in
max grade	10 %	14 %	20 %
max grade run	50 ft	50 ft	50 ft
max cross slope	3.5 %	5 %	8.3 %
obstacles	1 in	2 in	3 in

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A G-TUBE PUMP MOUNT FOR POWER AND MANUAL MOBILITY AIDS

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ABSTRACT

A gastrostomy tube (G-tube) is a surgical implant designed to deliver food directly to the stomach. An individual who has a G-tube is generally restricted to a mobility aid and dependent on caretakers for feeding and mobility. The food can be delivered to the stomach by force of gravity (by elevating the bag) or by using a pump which will deliver the food at a measured rate (i.e. Kangaroo pump). The rate of fluid delivery each individual can tolerate is highly variable. Since the client is dependent on the caretaker for nutrition, unless this entire system can be made mobile, the mobility of the caretaker and individual may be severely limited.

An I.V. pole mount that attaches securely to the mobility aid and will support a feeding pump and two feeding bags was designed. The mount is equipped with a telescoping I.V. pole and is angle adjustable from 0° to 45° to keep the pump mechanism and telescoping pole vertical.

Restricted mobility or inadequate mounting of the critical feeding hardware can seriously limit the mobility, independence, safety and quality of life of the client and care-giver. The I.V. pole mount is a versatile, aesthetically pleasing, functional product that enables mobility of the client even while feeding.

1.0 INTRODUCTION

The following details the development of an I.V. pole mount designed to solve a challenge faced by the children who require an intravenous or a gastrostomy feeding tube (G-tube). A G-tube is a surgical implant that delivers food directly to the stomach. The food is a nutritional fluid that is fed from an I.V. bag through an I.V. tube directly to the surgical implant in the stomach. The liquid can be propelled through the tube by gravity or a mechanical feeding pump (i.e. Kangaroo Pump).

The feeding rate for each individual is highly variable but can exceed 2 hours for a single meal. For clients who require a pumping system, the mobility and freedom of the caretakers and their dependent children is severely limited if they must remain stationary for the entire feeding period. Therefore, it is necessary to make the entire system mobile and easy to use even in motion. Since the vast majority of children with G-tubes are also dependent on caretakers for mobility, the primary method of transportation is with a mobility aid. Therefore, the system must attach to a mobility aid, typically a manual wheelchair. Since there are no commercially available systems to meet this need an adjustable wheelchair mounted feeding pole was developed. Table 1 illustrates the number of I.V. pole mounts requested since 1990, prior to the development of this product.

Year (April - March)	Number Requested	Number Provided	Number on Back Order
1990	7	4	3
1991	9	8	1
1992	16	9	7
1993	1	0	1
Total	33	21	12

Table 1 - History of Custom I.V. Pole Mounts

2.0 DESIGN CRITERIA

The following design criteria was established for the product. This criteria was established through experience from previous *one-of-a-kind* products prior to the decision to produce a generic design and in consultation with therapists and end-users of the product.

The product must retro-fit onto a variety of manual and power wheelchairs including rigid frame and foldable, tilt-in-space and reclining systems. The G-tube pole must mount permanently to the wheelchair so it is not lost. The I.V. pole must support at least 2 kg of fluid at full height and be height adjustable to allow for gravity feeding when necessary. The mounting system must support a variety the fluid pumps some of which must be vertical in order to function properly. The system must allow for easy removal of the pump when required and remain within the wheelbase of the wheelchair so as not to limit maneuverability. In order to be as versatile as possible, it must be mountable to various locations and in various configurations on the wheelchair. The entire system must be easy to install, easily accessible and usable by the caregiver. Finally, it must be aesthetically pleasing, and inexpensive.

3.0 DESIGN

The design of the I.V. pole mount was divided into three phases: the I.V. pole, the pump support, and the wheelchair interface.

3.1 I.V. Pole

A telescoping pole was required to achieve all design goals for the I.V. pole. The section lengths must be a minimum of 12" in order to accept the typical pumping systems. This section length limits the collapsed length of the pole (minimum height) yet enables sufficient height extension for gravity feeding (maximum height). A three section telescoping pole with height from 18" to 48" satisfied these requirements. A medium quality camera tripod provided three inexpensive, high quality, three-section telescoping legs with sufficient strength to support 4 kg at the full pole height of 48". When the tripod was disassembled, each pole was fixed with a 1/4" solid aluminium round bar bent into a hook. This hook was mounted to the pole by threading one end of the hook with a 1/4-20 dye which was then threaded into a 1/4-20 tapped hole in the end of the telescoping pole. This hook secured the fluid bag to the telescoping pole which was then height adjustable.

3.2 Pump Support

The pumps typically used to deliver the fluid (i.e. Kangaroo pumps) are designed to mount on an I.V. pole using a clamp capable of mounting to poles with outside diameter between 0.5" and 1.25". A telescoping pole with the same approximate outside diameter as a hospital stand-alone I.V. pole (outside diameter, O.D. approximately 1") so the pump can be mounted to this pole using the traditional pump clamp. The extension arm which provides angle adjustment and secures the I.V. pole to the wheelchair interface also provides a platform to further support the feeding pump. This pump support arm was constructed in three different lengths; 7", 8", and 9.5". These lengths were chosen to accommodate the different sizes of wheelchairs and seating systems onto which the system must be mounted in order to clear the seating system. It was critical to clear the seating system in order for the telescoping pole to be fully extended. The I.V. pole is secured to the mounting system using a clamp with 4 allen bolts counter-bored.

The cxtension/support arm has a groove milled along the length to reduce the weight and increase the aesthetics of the product.

3.3 Wheelchair Interface

The wheelchair interface secures the entire system mechanically to the wheelchair. For manoeuvrability, aesthetics and space constraints, the best location for mounting the system is to the rear of the seat-back canes extending backwards parallel to the rear wheels. Five main types of seat-back canes were targeted for mounting systems; 1" o.d. round bar (i.e. Kuschall, Quickie, and Zippie wheelchairs), 7/8" o.d. round bar, 3/4" o.d. round bar (i.e. Enduro wheelchairs), and large hexagonal bars (i.e. Mulholland Growth Guidance System), and 1" square extruded bar with 1/4" width track (i.e. Mulholland Variable Geometry Format wheelchair and Otto Bock MOSS seating system). Although the system is designed to mount to the seat-back canes extending back parallel to the rear wheels, these clamps could be mounted to any location deemed appropriate.

In order to mount to the seat-back canes of most wheelchairs, the clamps must fit between the seating system and the seat-back canes. Therefore the distance between the clamp hole and the front surface of the clamp was kept at a maximum of 7/16" in order to just accommodate two 1/4-20 allen bolts counter-bored. This is also the maximum distance between the two parallel 7/8" o.d. round bars of the Enduro wheelchair seat-back canes.

In order to keep the manufacturing costs low, the overall width and bolt hole locations of the wheelchair interface clamp was kept constant. However, the centre-line of the axis of the clamp hole was shifted in the clamp relative to the bolt holes in two ways. First the clamp hole was shifted closer to the front edge using equation (1) below to calculate the axis of symmetry for the clamp hole. Secondly, the exterior surface of the clamp was limited to 1/4" using equation (2) below to calculate the total thickness of the female half of the clamp.

$$AS = R_{max} + 7/16 \quad (1)$$

where, AS - Axis of symmetry of the clamp hole.
R_{max} - maximum distance between the axis of symmetry and the edge of the clamp hole (inches).

$$TT = R_{min} + 1/4 \quad (2)$$

where, TT - Total thickness of the female half of the wheelchair interface clamp (inches).
R_{min} - minimum distances between the axis of symmetry and edge of the clamp hole (inches).

This design allowed the clamp to fit between the seat-back canes and the seating system.

To keep the support arm for the pump vertical, no matter what the angle of the seat-back canes, an angle adjustment mechanism was incorporated into the clamp. The pivot point of the angle adjustment mechanism is constant. However, there are two locations to secure the bolt that slides in the track and therefore, adjusts the angle of the support arm. This allows the entire mechanism to mounted on either the left or right side of the wheelchair with the I.V. pole inside or outside the push handles. The angle adjustment possible is from 0° to 45° which from experience is sufficient for most children.

3.4 Entire System

With these design features the I.V. pole mounting system can be constructed and mounted in eight different configurations.

For aesthetics and abrasion resistance, the entire system is anodised black. Figure 1 illustrates the overall dimensions of the system. Table 2 illustrates the costs for production of these systems.

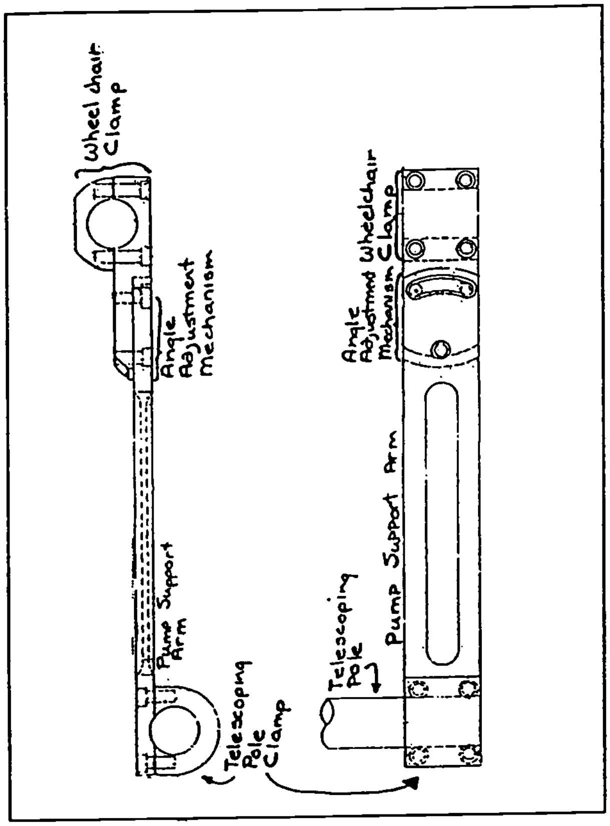

Figure 1 - G-tube Pump Mount

ITEM	COST PER UNIT
Mounting Hardware	$95.00
Raw Materials (Aluminium Rod, Aluminium Flat Bar)	$15.00
Telescoping Pole	$28.30
Fluid Bag Hook	$35.00
Design	$40.00
Assembly	$35.00
Administration	$20.00
TOTAL	$268.30

Table 2 - Production Costs

4.0 EVALUATION

At the time of printing, a total of 10 systems have been supplied. These systems have been mounted to Mulholland GGS and VGF systems, Quickie, and Enduro wheelchairs. The three length of the pump support arms have supplied sufficient length to support the pump and I.V. pole far enough from the seat-back canes to avoid the seating system when the I.V. pole is fully extended. All the clamps held the system securely to the wheelchair.

There was sufficient clearance between the seat-back and the seat-back canes to enable secure mounting of the system to the wheelchair seat-back canes. However, the space between the seating system and the wheelchair seat-back canes is highly variable and depends on the type of seating system and the mounting system used to secure the seating system to the wheelchair.

Except in extreme circumstances, there was sufficient angle adjustment to keep the pump vertical at the desired feeding position. Although in the first 10 mounts provided, this problem has not encountered, it could conceivably occur and for those clients requiring a seat-back tilt angle of greater than 45° for feeding, a custom systems would be required. The angle adjustment system held the pump and I.V. pole at the desired angle with no slippage.

The I.V. pole functioned perfectly supporting the fluid bags required. The minimum pole height was long enough to support all pumps used to this point.

Overall, the system is aesthetically pleasing, functional and inexpensive.

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Modifying the Subasis Bar to Enhance its Performance

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Abstract

This paper describes two modifications to a commercially available subasis bar assembly for enhancing its performance. The first modification reduces the overall diameter of the subasis from 1.625" to 0.750" to make its size more suitable for children and adolescents. The second modification converts the latching hardware of a swing-away subasis bar from a rear entry and latch mechanism to a front entry and latch mechanism, thus improving latching and unlatching without compromising fit. These two modifications have been made to a number of subasis bars with very positive results. Consequently, it is hoped that these modifications will be considered by the manufacturers and ultimately be incorporated into their manufacturing processes.

Background

One of the most challenging problems that seating and positioning professionals encounter is providing seating equipment that supports and maintains a proper pelvic position for the client. As many professionals will agree, a properly positioned and maintained pelvis is critical to the overall success of a seating intervention and outcome. Consequently, there are many seating devices that are designed to assist in positioning the client's pelvis and, more importantly, maintaining the proper pelvic position. One such device is known as the subasis bar.

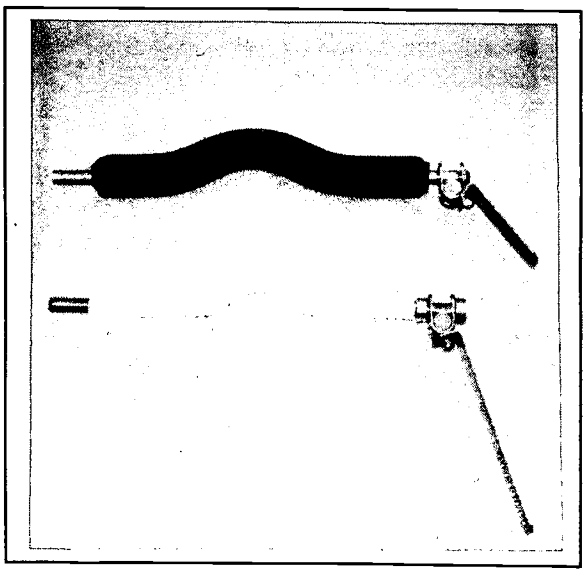

Figure 1

The subasis bar was first developed in 1983 by the Rehabilitation Engineering Department at University Hospital and Clinics, University of Wisconsin-Madison. Its development and use was presented at the 8th Annual Conference of the Rehabilitation Engineering Society of North America in a paper entitled *"The Subasis Bar: An Effective Approach to Pelvic Stabilization in Seated Positioning"*. As that paper and others describe, the intent of the subasis bar is to combat pelvic posterior tilt, pelvic obliquity, and/or pelvic rotation. This is accomplished by providing a posterior/inferior force at the pelvis in conjunction with other body positioning aids and associated forces. The pposterior/inferior force needs to be applied inferior to the anterior superior iliac spines (ASIS), as the terms subasis would suggest. In theory, use of a rigid, yet padded, bar to apply this force will result in improved pelvic positioning and maintenance.

Figure 2

Since 1983, subasis bars have been available commercially from companies such as Mulholland Positioning Systems; Snug Seat, Inc., which distribute the Techniseat line of componentry, Rehabilitation Designs, Inc. and Metalcraft Industries. In general, the subasis bar is a padded metal bar (or bars, as in the case of the Mulholland Pelvic Positioners) that is 1.625" to 1.850" in overall diameter. The diameter of the metal bars range from .570" to .750" depending on the manufacturer.

With the exception of the Pelvic Positioners manufactured by Mulholland Positioning Systems, the subasis bars are attached in one of two ways. The first method of attachment utilizes a mounting bracket on either side of the seat, into which the metal bar of the subasis bar slides and is held. The second method of attachment, ties the subasis bar on one side to the mounting bracket by means of a swivel joint. The subasis bar is then pivoted into the latch incorporated into the mounting bracket on the other side of the seat.

Clinical Considerations

Without question, the subasis bar has become an immensely valuable tool for clinicians and clients alike. It has proven effective in helping to position a client's pelvis and maintain that position over time. Unfortunately, however, the commercially available subasis bar does not work for everyone. For example, the large overall diameter of a commercially available subasis bar makes it difficult, if not impossible, to properly position on children and smaller-framed adolescents. Given the very small space between the inferior aspect of the ASIS and the proximal superior aspect of the thigh of a seated child, the subasis bar imparts unwanted force either on the bony ASIS or on the thigh.

As another example, the method by which the swing-away subasis bar is latched and unlatched hinders its fit on the client. The swing-away subasis bar is latched by means of a rear-entry latch which requires a 1.00" rearward and a .180" downward travel. Consequently, the subasis bar must fit loosely enough to accommodate this travel. But the clients' pelvis ultimately migrates forward, thus eliminating this free space and making unlatching difficult and painful.

Objective

In an effort to make the subasis bar more widely applicable, several commercially available subasis bars have been modified. The intent was to reduce the diameter of the subasis bar to make its size more suitable for children and adolescents as well as redesign the latching mechanism of the swing-away subasis bar to eliminate the problems associated with rear entry and latch.

Method

Diameter Reduction - Reducing the diameter of a subasis bar is a rather straightforward procedure. For the prototypes produced thus far, an Otto Bock S.T.S. Custom Ball and Rod (article #434F4) was used for the metal bar. The Custom Ball and Rod was used for its small .312" diameter, its availability, its weldability and its strength. It is made with an excellent alloy, possessing sufficient strength and rigidity required for the job.

First, the ball is cut off from the custom Ball and Rod, yielding a solid rod 17" in length. If midline relief is desired in the subasis bar, the rod is bent using the Otto Bock Bending Tool (article #711S6). The center bend is formed first, with a soft, rounded shape accomplished by moving the rod in the bending tool 1.5" to the left and right of center while operating the bending tool. The two outer bends are then made to create a shape that resembles a commrcial subasis bar. The rod is then cut to the length desired. This new bar becomes the core of the smaller diameter subasis bar.

The next step in the process facilitates the use of the original mounting hardware. .570" diameter steel stock, the diameter of the commercial subasis bar, is drilled along its radial axis to provide a .312" core. This stock is then cut in 2.00" lengths. These are placed over the ends of the smaller diameter rod and welded with the ends flush to provide a transition from the smaller rod to the original rod and mounting hardware dimensions. This new subasis bar, which possesses a core diameter of .312" can now be mounted to the existing hardware in the same manner as the original subasis bar..

To pad the new subasis bar, .250" thick neoplush is tightly wrapped around the .312" subasis bar and stitched. A cosmetic lycra cover is then stitched, turned inside out to hide the stitching and stretched over the neoplush padding. This results in a final diameter of only .750". A comparison of the commercial subasis and the reduced diameter version are shown in Figure 1.

Modifying the Subasis Bar

Latch Redesign - The latching method of the swing-away subasis bar has been converted from a rear entry and latch to a front entry and latch mechanism. The new design is modeled after a standard garden gate latch. The new latch mechanism has been made by taking a duplicate latch portion from the total piece of hardware and grinding it to the shape. It is then bolted to an original latch hardware facing in the opposite direction. For the prototypes, 8-32 nuts and bolts have been used. The latch hardware is then attached to the wheelchair or seating system in the normal manner, only reversed. Thus, the opening in the latch is facing forwards. The duplicate latch piece that has been attached simply swings upwards to allow access to the subasis bar and then swings back down to lock the bar in place. The process is repeated to unlatch the subasis bar. Consequently, the subasis bar now enters the latch from the front, rather than from the rear. A completed unit is shown in Figure 2.

Results

To date, seven smaller diameter subasis bars have been made and used with clients. These prototypes have been in use for over six months without presenting any mechanical problems. The smaller diameter bars are performing very well, providing a much improved fit to the client and actually reducing the tissue trauma or redness sometimes seen with subasis use. Even though the padding thickness and overall diameter is reduced, this has not posed a problem.

Two front entry and latch mechanisms have been built and are being used with clients. One of the two has been in use for eight months without developing mechanical problems. Both units have allowed the subasis bar to be better fit to the clients without hindering latching and unlatching. In fact, both sets of parents prefer the new mechanism, reporting that it is actually casier to latch. The true success of the new latch mechanism lies in the experience of one of the clients; where he once used to wince in anticipation of latching and unlatching, he no longer does so.

Conclusion

In conclusion, the two modifications to a commercially available subasis bar as described above have enhanced its performance and broadened its usability. The smaller diameter subasis results in a much improved fit to children, while the front entry and latch hardware for swing-away subasis bars results in an improved fit and function overall. The prototypes, in their current form, are not intended as final designs. Rather, they are intended to determine if a smaller dimension subasis bar and a front entry and latch mechanism is of value. If, in fact, these ideas are of value, it is hoped that commercial manufacturers will consider them and possibly incorporate them into their subasis bar product line.

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Case Studies of Performance Using Integrated and Distributed Controls

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ABSTRACT

Integrated controls can now be used to control several assistive devices through the same input device. Performance case studies were conducted with seven individuals who use multiple assistive devices to compare use of these devices with integrated controls and separate, 'distributed' controls. Integrated controls were found to be especially useful for those with severely limited control sites. Performance was not the most relevant factor in most decisions to integrate control.

BACKGROUND

With the wide variety of assistive technologies available, an individual with a disability may wish to access several devices in order to accomplish daily activities. Technology is now available to allow access to multiple assistive devices (e.g., ECU wheelchair) all through the same input device (e.g., joystick, sip-n-puff). This type of system is referred to as an 'integrated control' (IC) system. More common is a system in which each assistive device is controlled through a *separate* input device, referred to here as 'distributed control' (DC). ICs have recently been used for a variety of applications. For example, a study at the Hugh MacMillan Rehabilitation Centre is currently investigating the operation of a robotic arm through an integrated wheelchair controller.[1]

Since ICs are relatively new, there has been little empirical evidence to indicate when these systems are appropriate. Some researchers report that the benefits from using IC appear to be the greatest when the user has very limited ability to control movements to operate separate technologies.[1,2] While ICs may be beneficial for some, clinicians often must resort to a 'trial and error' approach to determine who these people are.

A three year project has been conducted at the REC on Technology for Children to determine the factors involved in recommending ICs. The first phase involved a retrospective review of 87 clients using multiple assistive devices.[2,3] The second phase aimed to explore these findings further through performance case studies of individuals whom therapists determined potentially appropriate for systems with either IC or DC. Participants' abilities to access multiple assistive devices were evaluated using both IC and DC, and the findings are summarized here.

METHODOLOGY

Participants. Seven individuals ranging from 10 to 38 years (average 20.4 years), participated in the study. Diagnoses included cerebral palsy, spinal cord injury, and congenital myopathy. All used powered mobility and at least one other assistive device (e.g., computer, communication device), and all were individuals whom clinicians deemed potentially appropriate for *either* IC or DC.

System Configurations. Participants evaluated two systems -- one with IC and a second with DC. One system had the access configuration recommended by the client's assistive technology team (PT, OT, rehab engineer and/or speech pathologist). The alternative configuration was established in consultation with these professionals for comparison during the performance study.

devices. Exercises on the communication device or computer were designed to evaluate skill in accessing a range of cells or keys. Performance measures included total time, # of incorrect cells accessed, # of cells missed on first attempt, and average # of attempts per cell.

Wheelchair exercises included performing tight circles around poles, 90 degree turns, 3-point turns, driving over an elevated sidewalk with no curb, driving up a ramp, and passing through a doorway. Performance measures included total time and # of 'corrective maneuvers' (e.g., swerves, repeat attempts, collisions). Wheelchair performance was only evaluated if a different wheelchair input device was substituted in the alternative system in order to allow access to both the wheelchair and the peripheral devices. Finally, the ability to switch back and forth between operating the wheelchair and other devices was also evaluated.

Procedure. Participants were given several practice sessions and then performed 12 trials of the communication or computer exercises, 4 trials of the switching exercises, and 4 trials of the wheelchair exercises (if necessary). These exercises were completed over several sessions and were administered for both IC and DC systems. The order of testing (IC vs DC) was varied. Performance was videotaped and was later reviewed and scored by two independent raters. Subjective data such as aesthetics, ease of use and independence afforded were obtained after the performance exercises.

RESULTS

Four of the seven participants preferred IC. However, performance was not found to be the single most important factor in the recommendation of IC; three of the four individuals performed as well or better with DC but preferred IC for other reasons. Those who preferred IC primarily became less physically tired during use of their other devices than when using a system with DCs. Other reasons included reduction in the number of input devices needed, easier postioning of switches, and greater independence resulting from decreased dependence on others to set up equipment interfaces.

Despite their preferences for IC, the use of ICs was not without trade-offs. These trade-offs included increased errors in computer access, and increased time to access the communication device and/or computer with an integrated system. However, participants reported that the trade-off in time was worthwhile because the decreased physical fatigue with IC allowed them to use other devices for much longer. Three of the four also reported that the IC system took longer to learn and greater concentration to use.

The other three participants preferred DC. The primary reason for this was that there was an unacceptable decline in performance on either the wheelchair and/or the peripheral device(s) with the IC system. One participant also had visual limitations which caused difficulties seeing the IC display.

DISCUSSION

While the use of a single, integrated input device is not appropriate for all assistive technology users, IC systems can be advantageous to certain individuals with disabilities. For example, for individuals who have only one site of control, IC can offer increased independence from the need to have different input devices swapped and repositioned frequently. For one individual in the performance study, the amount of hardware surrounding her, as well as the time for daily setup, were both reduced with the IC system.

The findings from the performance study and the retrospective review provide several general conclusions regarding the recommendation of IC systems. It must be recognized that these are merely guidelines, and that the evaluation of appropriate access and system configuration depends on the unique circumstances surrounding each individual client. First, when the site (e.g., head, foot) and input method (e.g., switch, sip-n-puff, mouthstick) of 'best' control for each assistive device (when evaluated independently) is the same, IC often makes sense.

Second, ICs are often appropriate for persons with only one site of control. Three participants had a single access site and, in all three cases, the use of a single, integrated control was less physically tiring than operating different devices from the same site, although it often resulted in more errors or longer time to operate other devices. This performance trade-off was found to be justifiable because of the reduction in fatigue and longer time this allowed individuals to use other devices.

Third, subjective factors such as personal preference or aesthetics may dictate the recommendation of ICs. One participant preferred IC because it provided him greater independence and minimized the 'clutter' of hardware around his head. Additional, more global factors suggesting the consideration of IC are discussed in detail elsewhere.[2]

The primary reason participants preferred the use of *separate* input devices (DCs) was performance-related. For the three who preferred DCs, it was found that performance on one or more assistive devices was degraded beyond an acceptable level when using an *integrated* input device. In general, performance trade-offs are likely to occur with an IC system whenever a less-than-optimum input site or method must be substituted in order to integrate control. A second reason for choosing a DC system may be its low cost relative to an IC system. Finally, while technical limitations of ICs were not typically problematic, the technical compatibility of equipment should always be determined before recommending IC.[2]

When properly recommended, ICs can improve an individual's ability to participate in all types of activities. However, the abilities, needs and desires of the client must be clearly established before the decision to integrate control can be addressed.

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A FOUR DEGREE OF FREEDOM PASSIVE DIGITIZER FOR CONTOURED SEATING SURFACES

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Abstract

The design, development and testing of a prototype device for digitizing contoured surfaces is presented. The device is a passive four degree of freedom articulated arm using rotary potentiometers for measurement of joint angles. It is designed for use in digitizing seat contours from molding seating systems. A prototype digitizing arm has been constructed and tested. Results from these test are presented.

Background and Introduction

This project began with an investigation aimed at determining the most appropriate technology for implementation of a low-cost digitizing system for use with seating simulators with moldable support surfaces. Several technologies including magnetic field detection, sonar and optical range sensing were considered. Considerations of these technologies were set aside for the simpler passive multi-degree of freedom (DOF) arm instrumented with rotary potentiometers. The passive multi-DOF arm has the best potential for developing into a reliable and inexpensive product because it is based on simple and proven technologies. Since the commencement of this project at least one low cost digitizing system based on this technology has been commercialized for use as an input device for computer systems. Digitizing arms with similar configurations, but manufactured to higher tolerances exist commercially as coordinate measuring machines. These devices are generally expensive, costing more than $10,000, but offer very high accuracy.

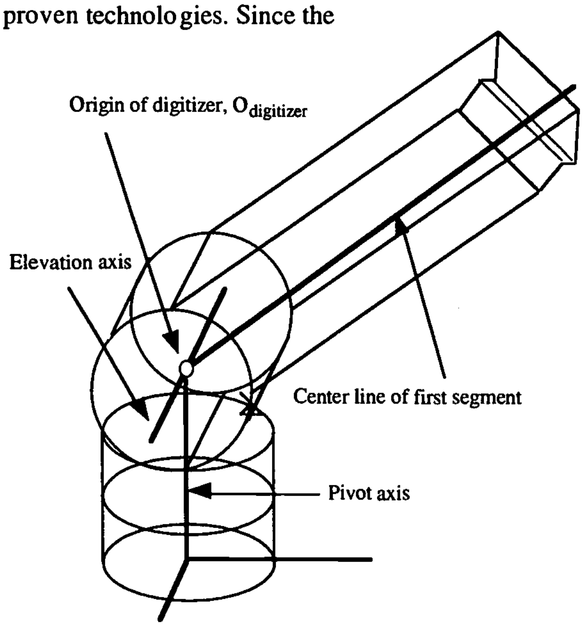

Fig. 1 - Digitizer Configuration

The first model digitizing arm was constructed in 1991 and successfully demonstrated the feasibility of the passive arm configuration for digitizing seat and back contour impressions. Part of this pilot project included the development of software to translate the angular measurements of the arm to 3-D cartesian coordinates and to display the information on the computer screen. This first model was a three DOF arm. Based on the model, a prototype three DOF arm was constructed and demonstrated at the 1993 RESNA conference in Las Vegas, Nevada. During the demonstrations it was determined that 3 DOFs were insufficient to capture all of the possible shapes presented by the simulator. Since that time a 4th DOF has been added to the model arm and evaluated.

Methods

The device is a four DOF arm with four revolute joints. The four joint angles will be referred to as the pivot, elevation, elbow and wrist angles. For the procedures described, the origin of the digitizer's coordinate system is defined to be at the intersection of the pivot axis, elevation axis, and center line of the first segment. (Fig. 1) The reference coordinate system is centered at the back right corner of the seat mounting pan of the simulator with the positive direction of the x-axis going from right to left and the positive direction of the y axis going back to front. All coordinate systems are right-handed.

The translational and rotational relationships between adjacent links of the arm are described using Devavit-Hartenburg matrix representation (Fu, 1987). Orthonormal cartesian coordinate systems are established for each link at its joint axis. Figure 2 shows the established coordinate systems. The fixed distance parameters for the arm are:

- a_2 the shortest distance between the axis of rotation for the elevation joint and the z axis of the fixed third joint;
- d_3 the distance between x-axis of the two coordinate frame to the x-axis of the upper arm coordinate frame.
- a_4 the shortest distance between the axis of rotation of the elbow joint and the z-axis of the probe end coordinate system;

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a_5 the shortest distance between the axis of rotation of the wrist joint and the z-axis of the probe end—fifth—coordinate system;

d_5 the distance between x-axis of the forth coordinate frame to the x-axis of the wrist coordinate frame.

The variable parameters are the joint angles; θ_1, the pivot angle; θ_2, the elevation angle; θ_4, the elbow joint angle; and, θ_5, the wrist joint angle.

The calibration involves three tasks:

1. Determining voltage-rotation gains for each of the potentiometers;

The gain is calculated by rotating each joint through a large, known angle and recording the change in voltage. The linearity of the potentiometer is specified by the manufacturer and was verified prior to assembly. The potentiometers used here have a linearity tolerance of ±0.5%. Potentiometer gains were determined in a similar fashion.

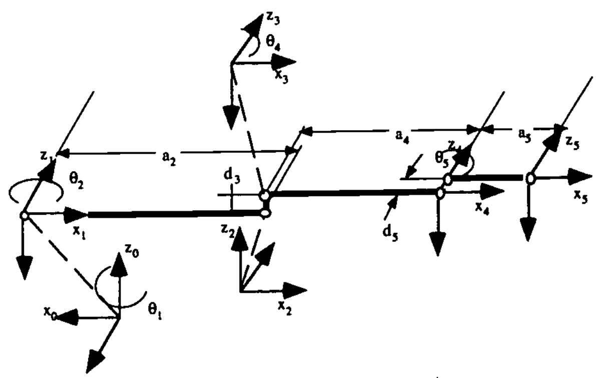

Fig. 2 - Joint coordinate system definitions

Joint	Θ	d	a	α	Range	Home (shown)
1	Θ_1	0	0	$-\pi/2$	unlimited	π
2	Θ_2	0	a_2	$\pi/2$	$-\pi/2$ to $\pi/2$	0
3	0	d_3	0	$-\pi/2$	fixed	N/A
4	Θ_4	0	a_4	0	0 to π	0
5	Θ_5	d_5	a_5	0	$-\pi$ to π	0

Table 1 - Link parameters

2. Determining reference voltages on the elevation, elbow and wrist potentiometers corresponding to known angles;

Reference voltage values are recorded for the potentiometers on the these joints. This involves making a correspondence between known voltages and known angles for the potentiometers. It is accomplished by providing mechanical stops for the joint rotation at known angles.

3. Determining the fixed distance parameters for the digitizing arm.

The dimensions of the digitizer that affect the distance parameters a_2, d_3, a_4, a_5, and d_5 need to be calibrated. To calibrate these parameters, a calibration setup would need to be constructed in which the digitizer could be mounted in a known orientation and at a known fixed distance from at least two calibration points. This setup would likely be costly and inconvenient. As an alternative, dimensions could be measured in the factory and entered into software as a one-time calibration. Of course this would eliminate the possibility of the user having the capability to recalibrate the device.

Determining the reference frame

Determining the reference frame for the digitizer involves finding the translation and rotation (location and orientation) of the digitizer base with respect to (w.r.t.) the reference coordinate frame. The following procedure is used. Assume that the distance between the elevation axis and the fixed third joint, a_2, the distance between the elbow joint and the wrist joint, a_4, the distance between the wrist joint and the probe end, a_5, and the offset distance, d_3, are all known. Also assume that the elbow joint angle, Θ_4, and the wrist joint angle, Θ_5, are calibrated and measurable. The distance from the probe end to the origin of the digitizer coordinate system is then defined.

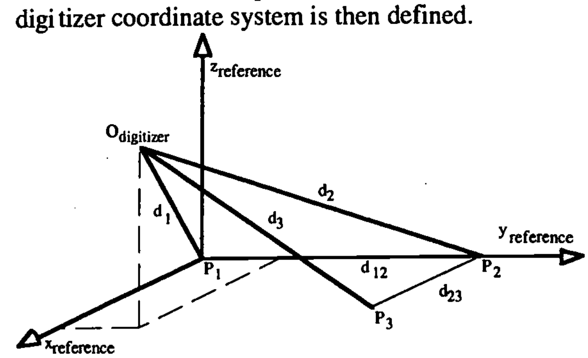

Fig. 3 - reference point definition

Define the reference points as follows: P_1 is origin of the reference coordinate system, P_2 is the reference point at the back left of the pan, and P_3 is the reference point at the front left of the pan. In Fig 3, the distance between P_1 and P_2, d_{12}, and the distance between P_2 and P_3, d_{23}, are known. d_1, d_2, and d_3 are the distances from $O_{digitizer}$ to the respective reference points.

The coordinates of the reference points, P_1, P_2, and P_3, in the reference coordinate system are (0,0,0), $(0,d_{12},0)$, and $(d_{23},d_{12},0)$ respectively. Solving the equations which define the distances from each point to the origin of the digitizer coordinate frame defines the reference point. Once the origin of the digitizer is known, the relationship between the reference coordinate frame and the digitizer coordinate frame can be computed using the 3 known points in the reference coordinate frame. The end of the digitizer—the probe end—is the origin of the 5th coordinate frame. The coordinate of this point w.r.t the digitizer coordinate frame is then uniquely defined. The coordinates of the reference points can then be determined w.r.t. the digitizer coordinate frame. A point in the reference coordinate frame is related to a point given w.r.t. the probe end by

$$P_{(x0,y0,z0)} = {}^{0}T_{1}\,{}^{1}T_{5}P_{(x5,y5,z5)}$$

where ${}^{i}T_{j}$ is the homogeneous transformation matrix relating the ith coordinate frame to the jth. and $P_{(xi,yi,zi)}$ is a point in the ith coordinate frame. Thus given the joint angles at each reference position, the transformation from the base coordinate system and the reference coordinate system is determined.

Mechanical Specifications

Link Lengths: The link lengths for the prototype are 22 in. for the lower arm, 22 in. for the upper arm, and 9.14 in. for the hand. Using these dimensions, the entire seat and back can be digitized comfortably without relocating and recalculating the base. If the back were reclined to an extreme position, a relocation of the digitizing base may be necessary.

Link Weights: The link mass should be minimized but rigid enough not to bend when subjected to moderate forces generated by the user. A weakness of the prototype is that the elbow joint is heavy making it difficult to control the arm while grasping the only the probe end. This also stressed the elevation joint likely decreasing the system accuracy. Using open frame potentiometers for the elbow and wrist joints would allow for a coupling arrangement which is simpler and lighter that the coupling used in the prototype for the elbow joint. The wrist joint of the prototype uses an alternate configuration that is lighter but introduces error because the shaft of the potentiometer is free to move in and out against retaining rings located on the shaft.

Spring biasing: The joints could be spring biased to counter act the weight of the links. At the very minimum the elbow joint should be spring biased if 4 degrees of freedom are used.

Other issues and Discussion:

Two methods for registering points were implemented. The first required that the user press the probe end into the seat surface for a point to be recorded. In this configuration, force on the digitizer end closed a microswitch located at the end of the probe which signaled the computer to record the point. The second method required that the user hold a push-button switch in one hand while passing the probe end over the seat surface. When the handheld push button was depressed the computer recorded the position of the end of the probe. The first method had the advantage of assuring that the probe end was in contact with something when a point was recorded. The second method allowed for more rapid data collection because the switch could be held closed while the probe was dragged over the surface. The number of points collected is limited by requiring that the probe move more than a preset threshold from the last recorded point before recording another point. A threshold of 0.5 in. was used for the evaluation .

Test Results

Two tests were performed to evaluate the accuracy and repeatability of the prototype . A test jig was constructed with 8 predefined test points spaced out over a range of 24x24x6 in.. The jig was placed on the pan of the simulator and held in place.

With the digitizing arm mounted on the simulator, the arm reference frame was determined by recording the angles of the arm joints while the probe end was positioned at the each of the three reference points. The probe was then moved to the corners of the plate and the four elevated test points in an arbitrary order. The computed location was recorded at each of the points. 4 to 8 readings were recorded for each test point. For first test the average absolute error was 0.49 in. with standard deviations ranging from 0.0 to 0.44 for the various test points. The test was repeated after repositioning the digitizing arm. The results from this test showed an average error of 0.69 in. with standard deviations ranging from 0.04 to 0.15.

Discussion

The accuracy for the prototype is less than the target of ±0.1 in. The repeatability is adequate. This suggests that a better calibration procedure is necessary. Weaknesses of the mechanical design stated above most likely account for some of the error. It is also likely that the choice of potentiometer adversely affected the accuracy of the system by requiring that the potentiometer shaft be used for the joint motion or be coupled to the shaft used for the joint motion.

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Technology Identification for a Non-Invasive Spinal/Pelvic Alignment Monitoring System for Individuals Seated in Personal Wheeled Mobility Devices

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Abstract

Spinal deformity can lead to loss of stability and upper body function, including a decrease in respiratory capacity. Effective non invasive procedures for measuring and recording spinal/pelvic alignment of a seated person are unavailable. The focus of this paper is to discuss possible methods of spinal/pelvic alignment measurement, and to evaluate the pros and cons of each method.

Background

Spinal deformity of individuals with spinal cord injury, and other disabilities such as cerebral palsy, muscular dystrophy or brain injury, can lead to loss of sitting stability, loss of upper body function, decrease in respiratory capacity, increased risk of pressure sores, and increased pain and discomfort. [1,2] Increasing numbers of prescribers and suppliers of seating and mobility devices are attempting to address these problems. Unsupported claims are often made that specialized seating inserts and cushions can reduce or inhibit the onset of spinal and/or pelvic deformity of individuals using wheeled mobility devices (WMD). More importantly, service providers and WMD users have no quantitative method of assessing either current status or past history of spinal/pelvic alignment while seated in their WMD. Serial x-rays taken at 3-6 month intervals are thought to expose clients to unacceptably high levels of radiation exposure, especially if follow-up is extended over a number of years. Determination of pelvic/spinal alignment is recognized as one the most important variables in special seating. It is important to be able to take the measurements while in the WMD, as the contribution of the seating support to the spinal/pelvic alignment is often the desired determinant.

Many non-invasive techniques have been tried to detect and measure scoliosis and kyphosis of the spine. Most of these techniques were developed to detect idiopathic scoliosis through screening of school age children. Among the more qualitative methods developed are the Scoliometer[3], Back Contour Device[4], Moiré topography[5] and thermography[6]. The more quantitative techniques have been surface topography [7], light beam scanning (ISIS)[8], and ultrasonic digitization[9]. All of these techniques have been compared to the "gold standard" of orthopedic radiographic spinal measurement, the Cobb method. Some techniques correlate better than others, with the conclusion by several investigators that the frequency of radiographs can be reduced, but not eliminated from spinal monitoring, especially for scoliotic curves that have progressed beyond a 30° Cobb angle. Good correlation between spinous process mapping and the Cobb measurements was demonstrated by Letts et al [12], for curves over 30°. Furthermore, they were able to demonstrate that an acceptable correction factor can be achieved for curves under 30°(Cobb).

The major limitation of these techniques is that they require direct exposure of the spine to the measurement instrumentation, preferably in the erect standing position. Radiographs require medical approval, are costly, and run the risk of excessive exposure. The preliminary literature review was unable to identify any technique or instrument that could measure and record spinal/pelvic alignment of a person seated in their WMD.

Objective

This objective of this project is to research, develop and evaluate a non-invasive monitoring instrument that could ultimately be used for the routine clinical assessment of spinal/pelvic alignment by service providers and WMD users. This objective will be accomplished by stating the engineering specifications the instrument must adhere to, identifying and evaluating possible technologies that could be used for monitoring spinal/ pelvic alignment, choosing the most appropriate technology, developing a prototype unit, conducting clinical trials and finally transferring a successful product to the marketplace.

Development of Engineering Specifications

The primary research challenge will be to locate and adapt existing advanced technology that will permit the rapid spinal/pelvic alignment measurement of a seated person with the minimal disruption to the existing service provision process. The problem can be reduced to identifying the coordinates of a curvilinear line in space relative to a know reference system, when this line is hidden within a known volume(chair and support system), that contains material of varied properties (air, support structure material, body tissues, clothes). It will probably be a desired feature to determine all the coordinates for the line at each instant in time and monitor changes as they occur (i.e:, in real time). Since this adds considerable complexity to the task, static measurements will be the first stage goal.

The spinous processes and anterior superior iliac spines (ASIS) and possibly other palpable bony prominences like the greater trochanters can be used with sufficient accuracy to represent the actual location of the spine and pelvis. The challenge that remains is to locate the markers on these prominences in 3-D coordinates while seated.

Using a wheelchair as the seating structure greatly complicates the determination of spinal alignment, yet it is precisely in this structure that this project proposes to determine alignment. Whatever analysis technique is used should be able to determine the alignment with respect to the wheelchair itself as a frame of reference. Visual inspection cannot be carried out since all wheelchair seat backs are opaque.

With the above considerations in mind the following specifications are established:

1. The technique will provide a quantitative 3-D image of spinal/pelvic alignment.

2. The technique will be non-invasive and non-ionizing.

3. The technique will be insensitive to the wheelchair system used during evaluation.

4. The technique will be insensitive to age or sex differences.

5. Resolution should be of the order of a few millimeters in each plane.

6. The time scan of the scan should be of the order of seconds.

Identification and Evaluation of Technologies

A search of existing imaging technologies was conducted to find possible methods of non invasively monitoring spinal alignment without a direct line of sight. Ultrasound was considered to be a possible candidate because since the speed is known, the time the ultrasound wave takes to reflect back to the source provides a quantitative measure of distance. However many wheelchair backs have foam cushions containing air pockets that would reflect the ultrasonic wave before it reaches the skin. Scanning from the front would allow interpolation of the spine position from the position of the ribs, but would not allow for determination of the pelvic alignment. Therefore ultrasound does not appear to be a practical technology for this project.

Eddy Current Sensing (ECS) was considered as a possible technology. ECS works by inducing a small current in a sensor and monitoring the disturbance caused by the sensor current on the emitter current. The sensors would likely be taped to a person's spinal column and the emitter would be outside of the wheelchair. The technology requires that the emitter increase in size as the distance from the sensor increases. Monitoring from outside the wheelchair would require a sensor too large in diameter to give results with adequate resolution. Also the sensor must be parallel to the emitter, which is impractical for individuals with seating misalignments. Recent improvements in ECS technology indicate that it may be possible to alleviate these problems. The status of eddy current sensors will be monitored while exploring other technologies.

A new imaging method termed millimeter wave technology has been developed that detects the natural 94GHz emissions from the body. The image produced is invisible to clothes, foam, upholstery and light weight plastics. The scan takes 1/30 of a second to complete. The technology was originally developed as surveillance equipment for airports to detect concealed weapons made of metal or heavy plastic, but could be used to produce a 3-D image of spinal/ pelvic alignment by placing metal tape on spinal landmarks and taking a stereo image of the spine from the back and the side to determine the 3-D coordinates of the landmarks. The technology will not be appropriate for chairs with metal insets in the back, however it allows images to be generated through backs with plastic or plywood inserts and sling backs. Investigation of this technology will continue to determine its appropriateness.

Discussion

At present there does not exist a non-invasive method of determining spinal/pelvic alignment of individuals seated in their personal wheelchairs. Successful development of a non-invasive method of monitoring spinal/pelvic alignment without a direct line of sight will provide clinicians with a feasible method of identifying and tracking spinal deformities. Present development is focused on choosing the most appropriate technology for the task. Clinical trials will follow after the development of a successful prototype.

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A LOW COST, ADJUSTABLE VACUUM FORM UNIT

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Abstract:

While vacuum forming has become a common method for upholstering custom contoured seating systems, several difficulties are common. The most problematic items include the cost of systems and accommodating the unusual and wide range of sizes of seating systems. Commercially available systems capable of handling a variety of different sized items are extremely expensive, and, while hand built systems are less costly, they frequently have weaknesses of their own. An inexpensive yet flexible vacuum form system has been constructed to overcome these drawbacks.

Background:

Commercially available vacuum form systems are expensive and are rarely an option for assistive technology providers who operate with very tight budgets. Most centers opt to construct their own systems using plans available from several different sources. While these are less expensive, they often have only a single frame size for vinyl which is always a compromise between the ability to accommodate larger systems yet not waste expensive vinyl and spray adhesive on smaller ones. Additionally, most plans include instructions for building a separate oven and table which can be dangerous and also allows heated vinyl additional time to cool before the vacuum is applied. Finally, in order to achieve adjustable vacuum, one is told to either purchase a rheostat controlled shop vac which is, again, very expensive, or to wire in their own rheostat on a less expensive model, which is not advisable unless a certified electrician is available.

Statement of the Problem:

Design and build a vacuum form system to meet these criteria:

(1) the cost would be kept to a minimum ,
(2) the oven and table would be constructed as a single unit,
(3) the table would be adjustable to accommodate the smallest and the largest seating systems without significant waste of vinyl .

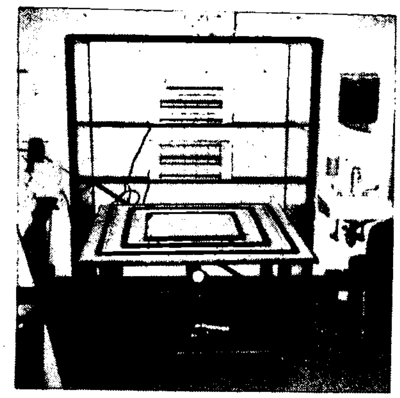

Figure 1. The completed vacuum form unit.

Figure 2. Staff vacuum forming using the small frame.

Low Cost, Adjustable Vacuum Form Unit

Design:

The table itself was designed as 4' x 4' and mounted on manufactured steel table legs. A 2 1/2" hole was cut in the center to accept a vacuum hose. A small shelf was added below the table for storing related items. The oven is a steel cage which surrounds the table on three sides and above. Both the left and right sides as well as the top are insulated with 1/2" solid panel insulation to prevent heat loss. The back of the cage holds one fixed and one vertically adjustable infra-red heater. The vertical adjustability is needed to evenly heat different sized sheets of vinyl. The heaters are both Fostoria 2100 watt 2 bulb heaters placed approximately 8" from the vinyl. Three frames for vinyl were constructed, one at 20" x 20", one at 30" x 30", and one at 40" x 40". Three different corresponding table frames were constructed with the smallest two removable for use of the different sized frames. A 3 h.p. shop vac was attached to the bottom of the table with a "T" fitting. The other side of the "T" fitting leads to a ball valve and a vacuum gauge which allows the operator to accurately control the amount of vacuum applied while still using a low cost single speed shop vac. Finally, a fluorescent light was attached to the table to provide good visibility under the insulated cage.

Discussion:

The system has been in regular use since September 1993 and results are positive. The different frame sizes allow for efficient use of vinyl while still accommodating oversized seating inserts. The smallest frame allows two sheets to be cut from the 56" width of vinyl used while the largest frame uses the entire width of vinyl. There is a narrow scrap left over when using the middle frame (which is the one most commonly used) which has allowed the upholstery of small items such as footrests and headrests without cutting additional vinyl from the roll. The twin infra-red heaters work well, heating evenly and without hot spots. The ball valve works well allowing high vacuum at first to create a seal, then using less later to avoid crushing the foam. Reinforcement is still used, however, on the back and sides of all inserts to prevent deformation.

Final costs include:

plywood	$32.00
table legs	$58.00
plumbing	$25.00
heaters	$480.00
insulation	$37.50
steel	$40.00
shop vac	$100.00

In addition to these costs, nearly 100 total hours over two weeks were used in the development and construction of the unit.

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Customized Integrated Control System

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ABSTRACT

This paper describes a modification to a Dufco Multimode switch input wheelchair control system. The system was customized to allow a young man with spastic quadriplegia to independently operate his wheelchair and a communication device.

BACKGROUND

Advances in power mobility control systems make it possible to control several different assistive technologies using the wheelchair input device. For example, it is possible for a user to operate a communication device, computer or environmental control unit (ECU) through the wheelchair's joystick or switches. A wheelchair with this capability is said to have an Integrated Control System (ICS). ICSs also offer performance adjustments, input device and driving mode options not always available with standard wheelchair control systems.

The availability ICSs has increased over the past few years. Six major wheelchair manufacturers are selling ICSs in the United States. Literature from many of the companies that sell switches, communication devices, ECUs and adapted computer equipment now discuss how this equipment can integrated with power mobility controls.

While integrating control of assistive devices may be beneficial, it is not always appropriate or feasible. Factors such as potential compromise in performance, cognitive demands, technical limitations, cost, and other factors need to be considered when deciding to use an ICS (1).

Client Information

Tung is a 16 year old young man with total body involved spastic cerebral palsy. He was referred to the rehabilitation team at CART for powered mobility and communication evaluations. Tung came to the evaluation with a PRC Light Talker which he had never been able to access. He was seated in an umbrella stroller in a reclined position, and was accompanied by his parents, Vietnamese immigrants who spoke little English.

Seating, Positioning and Access

The first issue addressed was Tung's positioning. He was taken out of the stroller and seated in an evaluation wheelchair. Tung was seated on a wedged Jay cushion with an abductor and left pelvic obliquity pad. The solid back was angled forward for a seat to back angle of approximately 80 degrees. His trunk was positioned using an Otto Bock over the shoulder padded chest harness and Freedom Designs trunk supports. He was also provided with a padded neck ring and a flat padded head support which helped to control his extensor tone. Due to his hamstring tightness, his feet were positioned on a solid footboard that supported his legs at a knee angle of approximately 60 degrees. Once positioned, Tung was able to access three switches, one positioned at his chin and two head switches positioned at each temple.

Mobility

We next looked at power mobility. Tung was seated in an Everest and Jennings Xcaliber. The wheelchair was equipped with a Dufco Multimode set up for switch input. Tung used the chin switch for forward, and the two head switches for left and right. With this setup and several training sessions he was able to maneuver the wheelchair forward, left and right. He displayed the ability to start and stop on command, follow a path, and correct his direction without assistance or verbal cuing.

This setup allowed Tung to control the wheelchair in three of four directions. In order to give Tung access to reverse he would need to be able to access a fourth switch, but Tung could not operate a fourth switch reliably enough to be used as a reverse switch. Nor could he operate a fourth switch that would allow him to change modes between forward and reverse, such as in a RIM control system. What was needed was a system that allows four directions to be controlled by only three switches. Dufco manufacturers such a system. With the Tri-switch control system, the user can toggle one switch between forward and reverse in any of the four available modes. While the Tri-switch can provide increased control for individuals who have access to only three switches, it's operation proved too complicated for Tung due to some cognitive limitations.

Integrating Control

Communication evaluation showed that he could best access his Light Talker using single switch scanning through the chin switch. Tung displayed some difficulty sequencing and problem solving. Multi-switch access for communication was not prescribed due to Tung's cognitive difficulties. It was also determined that Tung should use the same chin switch for communication as he would for power mobility, because it was not possible to mount two switches at his chin. To use the same switch to operate two different devices, Tung needed to be able to switch between a drive mode and a communication mode. This would need to be accomplished without the aid of a fourth switch (which he could not access). This could be accomplished through the use of input device mode selection and automatic reset.

Input device mode selection allows the user to select modes using his wheelchair joystick or switches. From standby, mode selection is accomplished using the input device. For example with the Multimode, the user would press and release the forward switch to select the drive mode. To return to standby the user waits a specified period of time without pressing any switches and the electronics automatically reset to standby, where the user can then select another mode.

When we looked at integrating Tung's communication device with the wheelchair electronics, we found another problem. Tung accesses his communication device using single switch, row/column scanning set at a very slow rate. While waiting for the cursor to reach a cell near the end of the display, Tung would have long pauses where he would not press his switch. While Tung was waiting for the cursor to reach these cells, the wheelchair electronics would often reset automatically taking him out of communication mode. Therefore he needed an ICS capable of bypassing the automatic reset while in communication mode but not in drive modes.

A system which allows the user to bypass the automatic reset in an accessory mode was desired. The Dufco Multimode has this capability and will stay in an accessory mode until the reset switch is pressed, but Tung could not access a reset switch. Another option is to set the automatic reset delay longer than any anticipated pause in scanning. Some systems allow the automatic reset time to be set to as long as 2 minutes, but the setting affects all modes. This means that the user would have to wait 2 minutes to change between any mode.

OBJECTIVES

What was desired was a wheelchair control system capable of addressing the following issues:

1) Control of four driving directions with only three switches,
2) ICS capable of accessing a Light Talker,
3) Mode selection using input switches (Input device mode selection),
4) Automatic reset in driving modes,
5) Communication mode with manual reset (bypassing automatic reset),
6) An electronics package that minimized cognitive demands.

METHOD/APPROACH

It was determined that optimum system for Tung was not commercially available. A Dufco Multimode switch input package was customized to meet Tung's unique needs. A system was designed based on three modes of operation, Drive Forward, Drive Reverse, and Communication.

A special switch input module was fabricated. A model 2775 Multimode display was ordered with an extra lead that was used as a sensor to tell the input module when the Multimode entered the Indoor drive mode. This lead was used to drive a relay in the input module, which switched the chin switch between forward and reverse. This means that the chin switch would drive the wheelchair backward in the Indoor mode, and forward in the Outdoor mode. The modes on the display were relabeled: Outdoor to Forward, Indoor to Reverse, and Auxiliary II to Communication.

Additionally, a model 3340 switch output controller was used to interface the Light Talker to the wheelchair. Output from the forward (chin) switch, was used to operate the communication device. The controller was set to bypass the automatic reset while in communication mode.

The wheelchair can only be returned to standby by activating a switch closure at the Multimode's reset jack. Although Tung could not access a fourth reset switch, he still had two unused switch closures (left and right head switches) in communication mode. The output from the right head switch was fed into the Multimode's reset jack and used to reset the chair to standby.

System Operation

The system starts in standby. To drive forward, Tung presses and releases his right head switch. This selects the Forward (Outdoor) mode. The chin switch will move the chair forward, and left and right are controlled through the head switches. Tung uses automatic reset to exit drive modes and return to standby. To drive backwards, Tung presses and releases his chin switch. This selects the Reverse (Indoor) mode. The chin switch will now move the chair backwards, and left and right are controlled through the head switches. To access the communication device, Tung presses and releases his left head switch. This selects the Communication (Auxiliary II) mode. The chin switch now activates the Light Talker and pressing the right head switch will reset the chair to standby. There is no automatic reset from Communication mode.

RESULTS/DISCUSSION

This system solved the problems described above and with the system Tung can independently drive and communicate. Using this system he can control the four driving directions with only three switches and access his Light Talker. Additionally, the system is not as cognitively demanding as other ICSs allowing Tung to easily and independently move between modes.

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THE EVOLUTION OF A MODULAR AUGMENTATIVE MOBILITY SYSTEM

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ABSTRACT

Over the past six years a modular augmentative mobility system (the "Smart Wheelchair") has been designed and evaluated with severely and multiply handicapped children. The design has evolved over this time through modifications and enhancements that emerged from the formative evaluation and developments within the rehabilitation field. We will look at the design, how it has changed and the factors that affected the change.

INTRODUCTION

The first prototype Smart Wheelchair was designed and built by the CALL Centre and the Bioengineering Centre, Edinburgh in 1987 to investigate the possible benefits and applications of augmentative mobility in providing severely disabled children with access to some degree of independent mobility [1]. The design grew in part out of the CALL Centre's service and research work in providing support to children, parents and professionals using augmentative communication aids and computer-based learning systems. We had found that even quite limited mobility (using a powered buggy) could motivate our young switch users to use and practice with their controls and more importantly to have fun doing so. This impression was supported by other studies using ordinary powered mobility aids. These had found the use of a powered mobility aid had a beneficial effect upon many aspects of a non-mobile child's life other than simply mobility. However, from the start we assumed that our users would be children who could not control a standard powered mobility aid for physical, cognitive or perceptual reasons, and therefore the powered wheelchair itself would have to be intelligent enough to: recognise and cope with dangerous situations and enhance the mobility experience for the pilot. We did not want to build an autonomous robot as this would have little educational or developmental (or, in our opinion, human) value. Our interest was in using motivation which we suspected was inherent in even quite limited mobility, to encourage development of physical skills (especially switch and control use); curiosity and exploratory behaviour; communicative initiative and general activity.

DESIGN

Our initial specification for the chair called for it to:

- Be capable of being operated by a wide variety of switches, scanners, augmentative communication aids and computers.
- Provide a safe environment for the user.
- Provide a range of functions that will enhance its use.
- Be capable of being tailored and adapted for individual users including during use as they develop new skills.
- Use existing components as far as possible.
- Be low-cost.

This all pointed to developing a 'tool-based' modular system [5], that can grow and adapt with the user and their environment.

A number of modules were envisioned, shown in figure 1 each of which would provide a number of tools:

- User interface that allows switches, joysticks, speech synthesisers and computers to be connected to the chair.
- Bumpers that detect collisions with objects.
- Line Follower, an IR-based device that follows reflective tape stuck to the floor.
- Rangefinders that provide 'slowdown', 'remote bump' and 'wall following' tools.

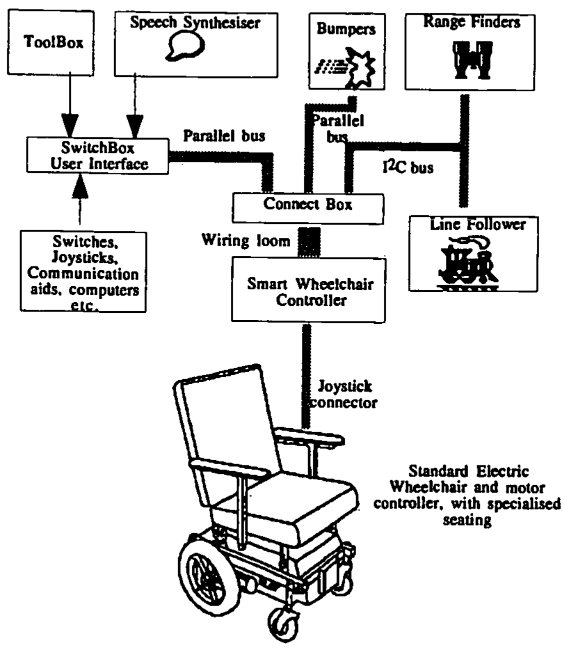

Figure 1 Smart Wheelchair Version 1

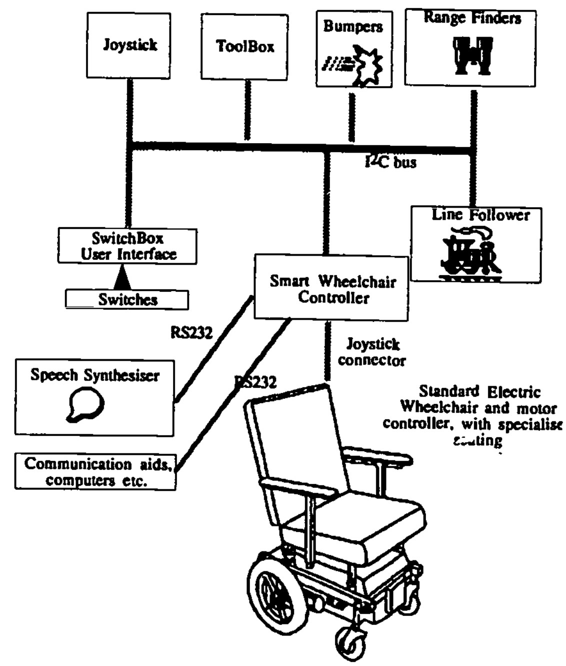

Figure 2 Smart Wheelchair Version 2

With the initial design of the chair as shown in figure 1, a number of different parallel and serial buses connect the modules together and major modifications had to be made to the chassis and motor controller [6]. Twelve versions of this chair were built and put into schools in Edinburgh for evaluation [7].

A number of problems were seen from this initial design: the build cost were high due to the chassis/controller modifications and the majority of modules requiring there own interface specification; reliability was impaired because of the number of cables and connectors and addition of new modules would probably require modifications to the design. It is to be noted that these problems were noticed early on in the build, but the first twelve chair were built to this design enabling them to be delivered early to the schools and the evaluation results fed back to the design team for modifications to be made, leading to version 2 of the design.

Version 2 of the design was based on expanding the I^2C interface [8], so that the user interface, tool setup and bumpers now communicated with the Smart Wheelchair Controller via it (figure 2). This coupled with making use of new versions of the motor controller that can accept remote joystick connectors also reduced the chassis/motor controller modifications to almost zero.

The new design also allows the chair to develop as new standards for the connection of rehabilitation devices emerge. Variants of the microcontroller used in the design have replaced the I^2C bus with the more robust, faster Controller Area Network serial bus currently being considered [9].

As well as changes to the overall design approach individual modules have also undergone change. One such module is the bumpers.

BUMPER DESIGN

The bumpers function is to detect when the chair collides with an object, ranging from solid walls to young children. As well as providing the obvious safety features the bumpers were also to enhance the functionality of the chair for the users, for instance, the chair could back away from an obstacle and turn to allow a user who only has the control to move in one direction to have a crude methods of movement (note the bumpers are used here for movement by deliberately colliding with an obstacle). The design had to be: sensitive to collisions, rapidly stopping the chair before damage occurs; robust enough to survive full-speed collisions with solid objects and provide an indication to the Smart Wheelchair Controller of the collision angle to enable it to try and get the user out of trouble. The bumpers are now in their third incarnation.

The first design used pneumatic sensors embedded in foam. These provided a good compromise between detecting collisions and absorbing the force of the collision, however they were bulky, expensive to manufacture and had reliability problems due to air leaks.

A cheaper design was built using force-sensitive material, this was embedded into the front of the foam. This was cheaper as the interconnection was simplified by using wires, but the sensitivity decreased and the robustness of the foam decreased.

The latest design uses pre-built conductive rubber (as used in powered doors) and it is hoped they will provide the same features as the pneumatic bumpers but with reduced cost and increased robustness.

CONCLUSIONS

Within the rehabilitation field, getting the design right without early evaluation and intervention with users is very difficult. The Smart Wheelchair has demonstrated that by putting a lot of effort at the beginning into the design philosophy and then quickly getting prototypes used by the intended clients using the feedback to improve the design, the end result is a device that meets the users needs, is cheap and easy to manufacture and will not become quickly obsolete.

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A TRACING HEAD/BARRIER AVOIDANCE SCHEME FOR A 3-AXIS AUTOMATIC SHAPE SENSING MACHINE FOR SPECIAL SEATING

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ABSTRACT

A tracing head with the capability to detect barriers was designed for a low cost, PC-based 3-axis motorized movement for automatic tracing of the contour of a moulding bag. When the tracing head encounters a barrier that it cannot surmount it sends a signal to the controlling PC which will then execute a barrier avoidance scheme.

BACKGROUND

A low-cost shape sensing machine for custom contoured body-supports was constructed to trace a moulding bag impressed with the contour of a client. The machine is simply an orthogonal 3-axis movement with a tracing head attached on the Z-axis. The tracing head consists of a commercial LVDT, a displacement transducer which has a free moving plunger, with a ball-probe attached at the end. The tracing head is driven by the 3-axis movement to ride along the moulding bag at fixed X-Y grid points and the 3-D coordinates are collected by a PC (1). It has been found that when the tracing head encountered either folds in a rubber moulding bag or steep gradients, there is a possibility that it will plough into the barrier. In the first case, the fold may be pushed up which results in an erroneous z-axis displacement reading. In the second case, the plunger may plough into the moulding bag and cause damage to either the bag or the sensor.

RATIONALE

A tracing head for this contact mode of tracing has to perform two functions. Firstly, it senses the change in Z-axis displacement which is assumed to be barrier free. Secondly, it should be able to detect any barrier in the X-Y plane. A barrier free assumption in one axis is reasonable in special seating because seat cushions and back-supports do not have 'over-hang' curves.

STATEMENT OF THE PROBLEM

Design a tracing head that will signal the controlling PC when it encounters a barrier that it cannot surmount so that the PC will take an appropriate corrective action.

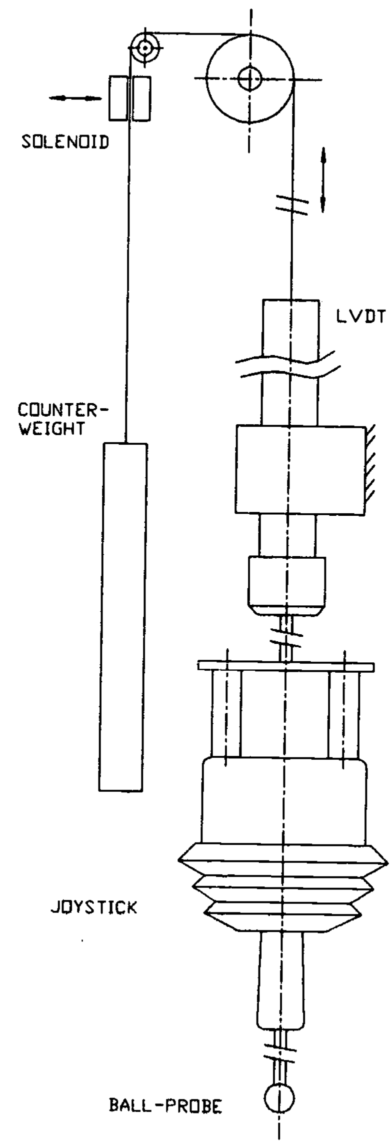

Fig. 1 Tracing head with barrier detection

DESIGN

The tracing head (Fig. 1) consists of a ball probe mounted on an inverted joystick (from an electric wheelchair). The joystick is in turn mounted at the

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end of the plunger of a ±50mm LVDT. Since the additional weight of the joystick decreases the ability of the tracing head to mount slopes, a counter weight is used to overcome this effect. The counter weight is connected to the plunger of the LVDT using a thin fishing line. To prevent the plunger from moving down when the tracing head has to move up either when the ±50mm range of the LVDT is exceeded or when the barrier avoidance scheme is activated, an electric solenoid is used to pinch the line.

When the tracing head encounters a barrier, the joystick is deflected. Joystick deflection is constantly monitored by the controlling PC (Fig. 2). If the tracing head cannot mount the barrier, the joystick will be deflected further. When the deflection exceeds a set limit, the barrier avoidance scheme will be taken by the PC. The active X or Y drive is first halted. He solenoid is activated to hold the probe before the tracing head is driven up 20mm by the Z-axis movement. Since grid points are 10mm apart, this amount of upward travel can accommodate a slope of over 63 degrees. If joystick deflection returns to preset limits, the tracing head is driven to the next grid point, otherwise the tracing head is moved up another 20mm and joystick deflection is again evaluated. If joystick deflection cannot return to preset limits when the tracing head assembly is moved up 80mm, the barrier is assumed to be insurmountable. If the joystick deflection lies within set limits when it reaches the next grid point, the solenoid will be de-energized and the probe is given time to fall down on the moulding bag.

EVALUATION

This barrier avoidance scheme is successful at the expense of time. The amount of extra time is dependent on the severity of the contour of the moulding bag.

DEVELOPMENT AND DISCUSSION

Since the LVDT is the most expensive device in the whole shape sensing machine, it is worthwhile to offer it extra protection from damage. This device

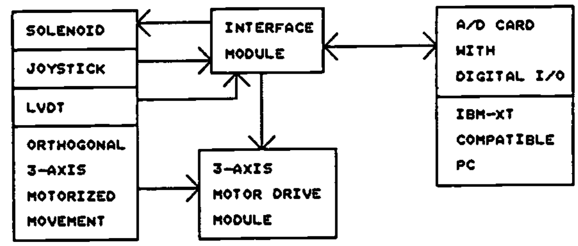

Fig. 2 Shape sensing machine block-diagram

is not designed to take a bending force judging from its construction. The plunger of the LVDT is made from a rather soft ferromagnetic material. It travels inside a hollow metallic core guided by a small plastic sleeve at the tail end and a hole in the front end-cap. We are now working on a design where the LVDT will not be subjected to any bending force. In this design, the ball-probe/joystick assembly is mounted at the low end of a stainless steel rod which is guided by two linear bearings. A horizontal plate is mounted on the top end of the rod. The LVDT plunger rests on top of the plate and monitors its vertical position.

The ultimate automatic tracing machine using a 3-axis movement would employ a non-contact sensing technique. The time it takes to trace a moulding bag will be greatly reduced because there is no need for barrier avoidance.

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TRAIL GUIDES WITH UNIVERSAL ACCESS INFORMATION

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ABSTRACT

Existing trail grading systems and maps do not provide persons that have mobility or visual limitations the objective information needed to determine if a trail can be hiked independently, with assistance, or not at all. The objective of the research project was to develop a format for disclosing accessibility information on outdoor recreation trails. Ten trail guides with universal access information on grade, cross slope, width, surface and obstacles were designed and developed. These unique trail guides will enable all outdoor enthusiasts, including those with mobility and visual limitations, to make informed decisions about which trails to use for recreational activities.

BACKGROUND

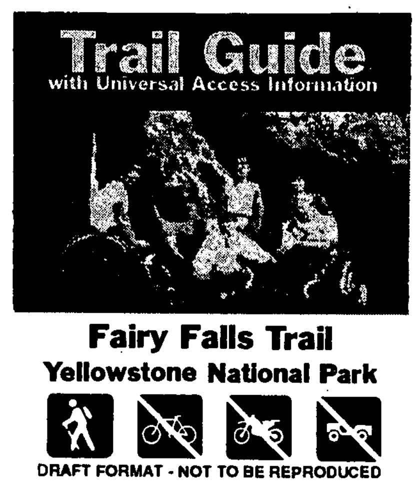
In 1990, the National Council on Disability held a public hearing addressing the need for improved access of parks and wilderness areas without excessive interference of nature. Wheelchair users do not want to see the wilderness paved (1). "Managing a wilderness area to provide special accommodations for persons with disabilities is not as important as marketing the concept that wilderness travel can be an appropriate and enjoyable form of recreation for persons with disabilities. The goal of land managers should be to provide a range of options that, to the extent possible, maximizes access without compromising wilderness." (2).

STATEMENT OF THE PROBLEM

Although there is an abundance of written material available on outdoor trails, this material tends to focus on the history, geology, and unique features of the trail. If a degree of difficulty of the trail is disclosed, the rating is usually based on subjective information. The difficulty ratings are not based on objectively measured data such as grade, cross slope, trail width, and surface type. Therefore, while a "moderately difficult trail" may be easy for an experienced hiker, it may be impossible for a wheelchair user.

RATIONALE

An important step towards providing access to trails for people with disabilities is to provide accurate information on the degree of accessibility of the environment. Approximately 13.3 million Americans have mobility limitations and about 2.8 million have sensory limitations that affect their level of activity (3). Most hikers, including those with physical limitations, desire a physical challenge and need information about the trail to decide what will be an appropriate challenge, and what will be impossible and/or not enjoyable. Objectively measuring existing trails and disclosing this information in trail guides with universal access information will allow people to choose not only where they can go, but also to choose an appropriate level of challenge.



Trail Guide front cover (Panel 1, 61% of actual size)

DESIGN & DEVELOPMENT

The computer generated trail guides contain text, symbols and graphical images, and incorporate universal design features to provide accessibility information for all trail users. The 8.5 by 14 in. trail guide folds in half three times to create a small package that can be carried easily on a hike. Helvetica 12 point text size and two contrasting colors, green and brown, are used throughout for easy readability. Franklin Gothic 14 point font headings allow for more rapid identification by persons with visual impairments who can then read more detailed text with a magnifier, if desired. Universal symbols were used whenever possible and 16 new symbols were created.

The full front panel of the trail guide is divided into six smaller panels separated by the fold lines. As the trail guide is unfolded, the panels are revealed in numerical order; the full back panel is contained on the reverse side.

Panel 6 Pict-o-gram		Panel 5 Trail information	
Panel 3 Statement of purpose	**Panel 4** Trail at a glance	**Panel 2** Back cover	**Panel 1** Front cover

Full Front Panel

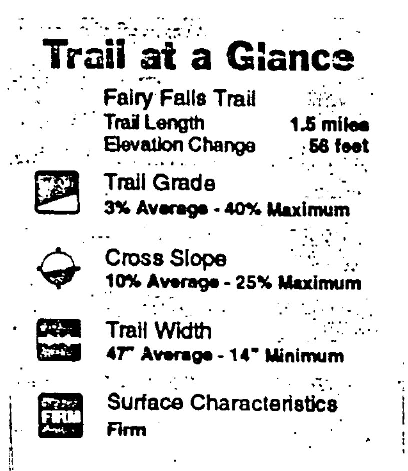
Top view with obstacle symbols	
Obstacle locations	**Profile** with surface information

Full Back Panel

Trail Title, Usage and Location (Panels 1 & 2)
The front cover contains the name of the trail, symbols indicating trail usage (means of mobility allowed and prohibited), and a picture of the volunteers that performed the assessment. The back cover shows the location of the trail to help hikers find the trail head and parking.

Statement of Purpose (Panel 3)
The statement of purpose discloses the date of the trail assessment and who performed the assessment. A disclaimer is stated, "Temporary obstacles such as fallen trees and landslides were not mapped. Trail conditions may have changed since the date this trail was assessed."

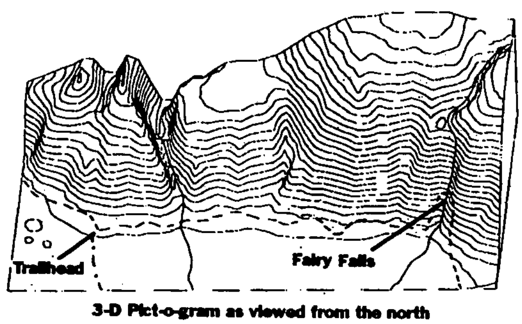
Trail at a Glance (Panel 4)
The trail at a glance contains a summary of the objective measurements made during the trail assessment: trail length, change in elevation, grade, cross slope, width, and surface characteristics.



Trail at a glance (Panel 4, 61% of actual size)

Trail Information Text (Panel 5)
This section contains general information about: 1) available services such as parking, toilets, and water; 2) points of interest along the trail including plants, trees, and flowers; 3) the history of the trail; and 4) other trails that intersect the main trail.

Pict-o-gram (Panel 6)
The pict-o-gram is a parallel grid mesh map showing the trail in reference to surrounding terrain, rivers and other bodies of water. This three dimensional map provides the user with a "bird's eye" view of the trail.



Pict-o-gram (Panel 6, 41% of actual size)

Top View Information Map
This map is a top view of the trail. The legend defines all line types and symbols. The location of the trail head, points of interest, roads, rivers, and other bodies of water are clearly labeled with text. Along the trail, markers show the distance from the trail head. Symbols indicate obstacles along the trail and code objective information on grade, cross slope, surface type, and trail width.

Obstacle Locations and Other Information
The Obstacle Locations section gives more detailed information about obstacles encountered along the trail. Areas with severe grades, severe cross slopes or narrow widths are noted so that hikers can determine how far they can go before encountering a less accessible part of the trail. The Other Obstacles section lists the types and sizes of obstacles found throughout the entire trail. The percentage of the trail that exceeds a specific grade or cross slope or is less than a given width is also disclosed.

Profile with Surface Information
The profile shows a side view of the trail and the change in elevation. A 1:12 (one inch rise to 12 inches of length or 8.3%) reference angle is depicted next to the profile to enable users to compare the trail conditions with the more familiar standard ramp angle. The area below the profile is shaded according to the type of surface found on the trail: hard, firm, soft, and very soft. Mileage markers identify key points along the trail profile such as the trail head,

other trail intersections, and points of interest.

EVALUATION

The development of the overall layout of the trail guides and the individual map elements, including graphical representation of trail information, symbols and text, was guided by feedback received at design reviews. The trail guide underwent several design revisions based upon feedback received at 17 design reviews. The reviewers included: trail users, persons responsible for trail management, wheelchair users, persons with visual impairments, accessibility experts, and graphic designers. The trail guides were presented to several prominent groups working on accessibility of trails including: USDA Forest Service, USDI National Park Service, and the Access Board Advisory Subcommittee on Outdoor Recreation.

DISCUSSION

These unique trail guides will provide persons with and without disabilities adequate information for selecting trails with the desired degree of challenge that will result in a fulfilling outdoor experience. This work has had a national impact on raising awareness and provoking action to increase the available information about the degree of accessibility of outdoor recreational trails.

Future work includes a thorough evaluation of the trail guides by persons with disabilities. Further design input will come from field testing involving persons of all physical abilities, including wheelchair users and persons with visual impairments, using the trail guides while hiking the trails.

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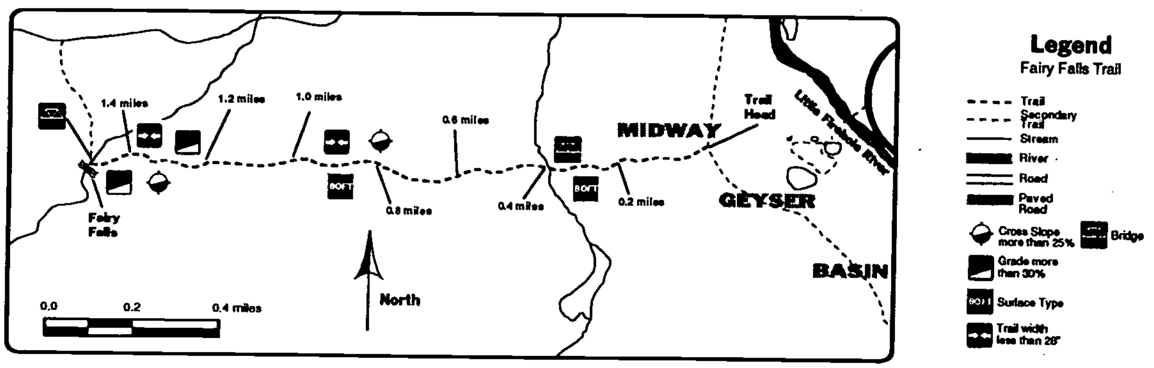
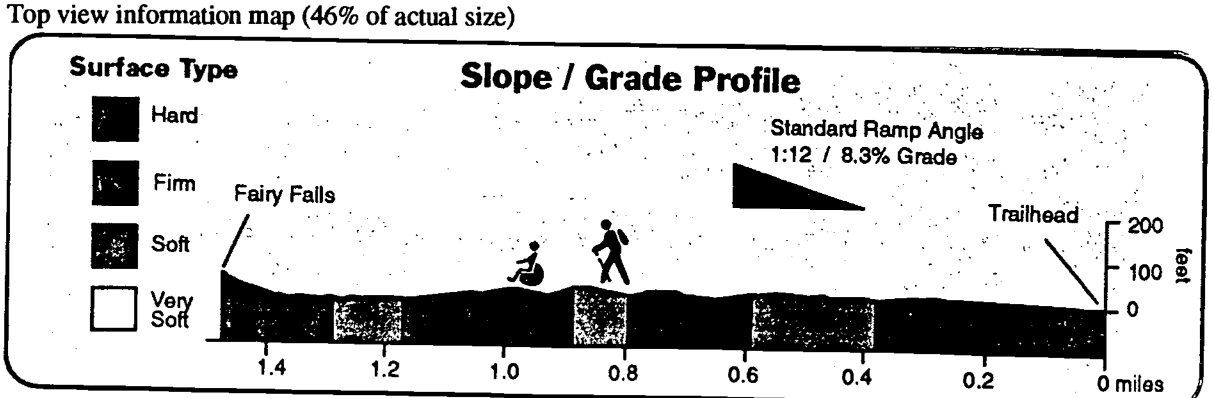


Top view information map (46% of actual size)



Profile with surface information (67% of actual size)

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A FLEXIBLE INTEGRATED ACCESS SYSTEM

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Abstract

Many people use switches to operate their communication aid. Several have expressed a wish to use their switches and switch skills to drive a powered chair and operate other devices such as environmental control systems independently. Most integrated systems currently available are too limiting and don't easily interface with existing third party equipment. A flexible integrated system has been developed that allows use of a switch system both to control a powered chair and to operate other devices independently. A built in infra red transmitter allows the switches to be used to operate common remote devices such as environmental control systems. Developments have been made throughout the project resulting from the feedback obtained from individuals using this system. The system is described and discussed.

Background

Many physically disabled individuals are able to acquire some level of control and independence over their lives by the use of switches. Using switches the individual may be able to access a number of technological aids to living. There are many such aids on the market, each focusing on one aspect of typical daily living needs. Such needs include mobility, communication, written material and independence in the home. Each of these needs can be met with a variety of different devices: powered chairs, communication aids, computers and environmental control units.

A problem arises for those users wishing to operate more than one system; In many cases the user is presented with a sperate switch system to operate the additional equipment. Alternatively the user's existing switches may be connected manually by an attendant to the desired device. Both these situations are generally unsatisfactory and do not facilitate independence.

Further problems are encountered when the user wants to drive a powered chair and is faced with a joystick. For many switch users, but not all, this can be too difficult.

The importance of mobility and communication for learning in children can not be underestimated (1). They provide for greater independence and can lead to employment as an adult. They are also important motivators, providing fun and a sense of achievement.

Although there are integrated control systems available they are usually chair based such as the Permobile chairs(2) requiring the individual to use a particular chair. Not only does this limit choice but the individual may find some of the chair characteristics unsuitable for their needs. Other integrated systems tend to be one off systems made for a particular individual with specific needs (3). This potentially has the problem of inflexibility when it comes to the changing needs of the individual. Not only may the individual's physical skills change, but also the devices being operated.

Much work has been done towards integrated systems based on a bus model (4). This is about standardising the interconnections and transmission protocol of devices so they can be hung on the bus like a network.

Statement of problem

What is needed is a flexible integrated system that enables an individual to operate a variety of devices with the same switch system. It must cope with varying switch skills and easily interface to a wide range of powered chairs.

Rational

A flexible system must be able to interface with a variety of third party equipment. This means being able to directly connect to devices such as switch operated communication aids. It also means being able to interface to environmental control systems remotely via a wireless link.

Although the same switch system is to be used, different devices require different skills for appropriate and effective operation. An effective integrated system needs to match the physical skills of the individual to the input requirements of the various devices to be operated. For example a communication aid may require many switch activations over a period of time making speed and accuracy important variables. An environmental control system will typically be used much less often making speed of access less important. The skills required to drive a powered chair can be different again with safety being of paramount importance.

Design

A device has been designed that will enable a powered chair to be driven by an individual using a switch or combination of switches. The device also enables the individual to control a number of other devices using the same switches. These include four remote control infra red channels, three switch channels and a built in buzzer for attention calling.

Hardware description

To enable a powered chair to be driven the system must interface with the chair's control box. The Dynamic Controls DM series of control boxes was chosen since it is of good quality and commonly available world wide. The Dynamics Controls control box connects to the chair via a standard beau connector. Although the system must interface to this range of control boxes these will directly connect to a very large variety of chairs.

The system is housed in a black box 1 1/2" deep with a front face of 6 1/2" X 4". Amongst other things it completely emulates a joystick control. It has an illuminated on/off switch, a chair speed control speed and direction control. Covering the front face are eight bright 1cm LEDs in a diamond formation and one LED in the corner. This LED in the corner is the Mode LED. The LEDs were chosen and positioned for easy viewing for both indoor and outdoor use. The LEDs not only represent chair direction but also indicate what other devices the switches may be operating. On the reverse of the box are two infra red LEDs. A mounting bracket forms part of the box casing. The user's switches connect to the system via a seven pin DIN socket on the side of the box. Also on the sides of the unit are three 3.5mm sockets that can be connected to, for example, the switch input of a communication aid.

At the heart of the electronics circuitry is a 68HC11 micro-controller with code written in assembly language. The whole circuit fits on a card 160mm by 100mm. The components are mounted on one side and the LEDs are mounted on the other. The only flying lead that is connected to the card is a cable that connects to the powered chair's control box. All other sockets are board mounted.

Operational description

At its most basic the system will enable an individual with a single switch to drive a chair and have control of up to eight other devices. The LEDs will automatically scan the LEDs indicating possible directions. When the desired direction is indicated the switch is hit and the chair moves in that direction. The chair will move for as long as the switch remains active or as long as the system's adjustable "time out" safety feature cuts in and stops the chair. There are a number of other methods of driving the chair using anything up to five switches. Some methods involve the LEDs to automatically scan, others are more direct. A three switch method uses a combination of the two. In this configuration a distinction is made between driving the chair and manouevering the chair.

The way in which the individual determines which other device to operate also depends on the switch-scanning configuration that the individual has chosen. Whichever method is chosen the Mode LED will illuminate indicating that the individuals switches are not going to drive the chair but will operate another device. The four infra red channels have been set as default to operate the environmental control systems most commonly available in the UK.

Safety features

A number of safety features have been incorporated in the design of the system. These broadly fall into two categories: those that are user related and those that are inherent within the system design. The inherent features include such things as automatically turning the chair controller off when the system is not in chair drive mode. The principal user related features are the "Time out" feature, and the "Switch check-up procedure". The "Time out" feature simply stops the chair moving after a pre-set period of time while the driving switch is held active. This means that if the switch failed in the active position the chair will eventually stop. There is an adjustment provided for altering this time. The individual also has the option of disabling this feature during the "Switch check-up procedure". The "Switch check-up procedure" is a way in which the system checks to see if the individual's switches are plugged in and working properly. It is forced into this procedure whenever power is applied to the unit or whenever an adjustment is made such as altering the "Time out" time.

Evaluation

To date there are approximately 20 of these systems being used. About 10 of these have been altered from the original specification to accommodate the specific needs of the individuals concerned. Most of these alterations are now available as "dip switch" options making the system very flexible and comprehensive. The two areas of most change and comment were: the input switch scanning configurations and the safety features.

Initially it was intended as a device for people who typically used a communication aid with one or two switches. However, it soon became clear that the skills required to drive a chair were different from those required to operate a communication aid. Also some people were using a switch scanning configuration dictated by the communication aid. Many people came back to me telling me how they would like to drive the chair. This led to several people using their switches in a different way for different devices.

The safety features previously described are there to try to accommodate catastrophic switch failures. It was soon realised that the "time out" feature was sometimes not appropriate, particularly outdoors. This was later rectified by providing the option for the user to accept the current "time out" value or disable the feature altogether. It also became apparent that the weakest link in the system were the switches which were generally provided by the user. Sometimes these were badly made and unreliable. The "switch check-up" routine was introduced to take care of this. So far no complaints have been received about this.

Discussion

The integrated system described is based on a needs led approach.

It connects to a standard widely available control box. Although this makes the control box dependent it is not chair dependent since it can be fitted to almost any powered chair.

There are a wide range of switch-scanning options available. This enables an individual to drive a powered chair in the most efficient and appropriate way regardless of how s/he operates other devices.

The system is capable of being connected to standard communication aids and operating standard environmental control systems via a remote controlled link.

There is enough flexibility in the basic circuit design to allow for one off personalised systems to be made should the need arise

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SAFETY VERSUS FUNCTIONALITY, A EUROPEAN DISCUSSION ON STANDARDS FOR WHEELCHAIRS AND RELATED PRODUCTS

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ABSTRACT

Within Europe, wheelchair safety standards are under development. These standards will specify the safety requirements to be met by wheelchairs that will be marketed within the European Community. In these standards an optimal balance between mobility and safety of the wheelchair user has to be established. A short overview of the European stituation is given, and relevant aspects in finding the proper balance of safety and mobility are discussed.

BACKGROUND

In the development of product safety standards it is quite a challenge to find a satisfactory balance between the interests of the consumers and the abilities of the manufacturers (1). For safety standards for mobility devices an even more critical balance has to be reached: the balance between safety and usability of the product. Fitzsimmons (2) already described a discrepancy between the normally accepted level of risk, and the level of risk to be accepted by persons with disabilities for external, society defined interactions like traffic participation or public transportation.
It is discussed that, also in not external enforced situations, users of mobility devices are willing to accept higher (personal) risk levels if leading to an attractive increase of their mobility.
Initiated by the new European legislation with respect to safety of medical devices, discussions to find an appropriate balance between the safety and the usability of mobility products arised.

Normalisation in Europe

The Medical Devices Directive, put in force mid 1993, regulates the product safety of medical devices within the European Community (3). This regulation also includes rehabilitation products. It specifies rather general the safety requirements to be met for dissemination of products within the European Community. The requirements are stated as so called "Essential Requirements". Manufacturers will have to declare conformity to these Essential Requirements (ER's). To indicate conformity with the provisions of the Medical Device Directive, the products sold in Europe should bear a CE-mark. The conformity assessment procedures for devices like wheelchairs can, as a general rule, be carried out under the sole responsibility of the manufacturers. Whereas for other products, constituting a higher risk potential to the user, the intervention of a certification body is necessary. The main essence of the ER's can be summarized by (3):

- the product must be safe
- the product must achieve the performance intended by the manufacturer

The detailing of the ER's is commissioned to the relevant committees of the European Standardization Institute (CEN). The standards to be developed are divided into three hierarchic levels, mainly based on the product range included. The first level covers the general safety aspects applicable to a wide range of related products, i.e. all rehabilitation products. This standard will include requirements with respect to issues like ignitability, sharp edges, pinch points, etc. In the second level standards, additional requirements will be set, focusing on one product range, i.e handdriven or electrical wheelchairs. Special products within such product range, i.e. lever-wheelchairs, are dealt with in the third level standards.
Mid 1992, a CEN-working group has been established to develop level 2 standards for handdriven and electrical wheelchairs, scooters and microcars.

Wheelchair market in Europe

The European wheelchair market can be characterised as a so called "sellers market". There is little direct interaction between the manufactures and the users. For example in the Scandinavic countries and in the Netherlands, most wheelchairs are supplied at indication of prescribers of (semi-) Governmental institutions. To support the prescriber in their task, product evaluation systems have been developed in these countries, at (semi-) homologation level. Since these product evaluations are intended to support the prescriber, many user related aspects are incorporated. In some other European countries, only products provided to veterans are subjected to evaluation procedures (5).
Starting from this background, the new European wheelchair standards are developed to ensure the safety and compliance to the designated purpose.

Safety versus functionality
Requirements only related to product construction i.e. strength and durability, electrical safety and climate resistance, are discussed for long time in (inter)national normalization bodies. Definition of these requirements is mostly a matter of finding a final balance between the interests of the consumers and of the manufacturers. However, the development of safety standards for mobility devices asks for more than only constructional requirements. The product performance should be critically examined with respect to all potential hazardous situations. These safety standards will only be successful if a proper balance has been established between a minimum acceptable safety level and the related functionality of the product for the intended user. Or in other words, the risks associated with the use of the device must be in accordance with the mobility gain of the user.

This fragile balance is illustrated in the following examples:

- To decrease the driving effort and enlarge the manoeuvrability of handdriven wheelchairs, a forward position of the rear wheel is preferable, but this situation creates a higher risk of tipping backwards.
- The braking performance of electrical wheelchairs and scooters is generally accepted to be a safety issue (5), determined in relation to safe traffic participation. New electronic developments make it possible to change easily the braking performance of each wheelchair to the customers needs. Question is whether deviation from the defined minimum safety level is acceptable. The balance between the user's advantage and the increase of risk level of both the user himself as well as the risk for passers-by should be within acceptable limits.

In the weighing process also the availability of other solutions with minor or without effects at the safety level should be taken into account.

- In the example of braking performance, combined reduction of maximum speed leads to a slight decrease of mobility but maintains the minimum of safety level.

The situation becomes even more complicated if operatability and long term health effects are included in the risk assessment. These aspects add another dimension to the balance: the diversity of the users. Not properly stated requirements for operatability and ergonomics might lead to exclusion of products or design solutions, that serve the needs of specific user groups. In example:

- For elderly, making a forward transfer, it is a real safety issue that footrests can be easily removed during transfer. For users making sideways transfers this is of no relevance. For them it is more important to have a save side-ways transfer area without any pin-points like brake levers protruding above the seat.

DISCUSSION
The above mentioned problems are not exclusive for the new CEN-working group. All (inter)national standardization groups and prescribers have encountered similar questions.
The most common used solution, is to delegate more responsibility to the user and/or prescriber by making relevant information about products available. However, this turn over is only acceptable if the information receiver is capable of correct interpretation and application of the given information. Within the ISO-working group a rating of testmethods is developed which clearly shows the preference for this solution (6). To evaluate the priority of tests, the profit by means of information useful for decision making, is given equal importance as a combined rating for safety, loss of independence and user inconvenience together (6).

The dissemination of information to the user is also of prime importance for the development of a more "buyers" oriented wheelchair market in Europe. Better confrontation with the users needs is expected to challenge the manufacturers to come forth with innovative products and new designs solutions. The process of product innovation itself will be a good stimulus for creativity in standards development since most innovations will touch the edges of the current accepted requirements.

Another important key towards the problem is the classification of the intended use of the product. This method fits very well to the methodology of the Medical Device Directive, as worded in Essential Requirements: "The device must achieve the performances intended by the manufacturer" (3).
The development of differentiated requirements is facilitated by the definition of several classes of standardized intended use. The most obvious example of this solution is the classification of in- and outdoor use for electrical wheelchairs. Outdoor wheelchairs are expected to be capable of safely coping with steeper slopes, higher obstacles, etc.
The definition of standardized intended use also facilitates the manufacturer to declare conformity to the Essential Requirement that a product must achieve the performance intended by the manufacturer.

SAFETY VERSUS FUNCTIONALITY

Analysis of accident information is usefull either to detect a discrepancy between safety and functionality or to support the decision making proces of relevant requirements. In example, it is known from accident registration in the Netherlands that 35% of all accidents with wheelchairs and walking aids, registered at the first aid department of Dutch hospitals, are caused by "falling out of the wheelchair" (4). The analysis itself gives not enough information to base requirements upon directly, but it highlights the need for risk analysis of a situation not given much attention to in standards until now.

SYNTHESES

The wheelchair standards that have to be developed in Europe, to ensure safety and compliancy to the intended performance as defined in the Medical Device Directive, should not only focus on safety aspects but also cause a need to disseminate relevant information to the users. This is important in order to create a more "buyer" involved market which is assumed to have a positive spin-off towards relevant product innovation.

On the other hand, extension of involvement of the user in the safety aspects of wheelchairs by disclosure of information, should not lead to avoidance of difficult safety questions, leading to incompleteness of the resulting standards.
Classification of the intended use is given as a method to develop relevant requirements, related to the environment and usage of the product.

This discussion is expected to contribute to the development of standards associated with an optimal balance between mobility and safety of the wheelchair user.

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EFFECT OF CAMBER ON WHEELCHAIR STABILITY

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ABSTRACT

Negative rear-wheel camber (the extent to which the tops of the rear propelling wheels of manually-propelled wheelchairs are angled inwards) has become increasingly popular. However, the consequences on stability have not been reported. We have tested the static lateral, forward and rear stability of a lightweight wheelchair occupied by an anthropomorphic testing dummy, at camber angles ranging from +15° to -15°. As camber becomes more negative, lateral stability increases (R^2 = 99.7%). Surprisingly, forward stability also increases (R^2 = 88.9%) and rear stability (brakes locked and unlocked) decreases (R^2 = 96.5-96.9%).

BACKGROUND

Negative camber of the rear wheels (angling the tops of these wheels inwards) is a feature of approximately 20% of manually-propelled wheelchairs (data unpublished). Camber affects rolling resistance (1,2), kinematic and metabolic efficiency (due to the abducted arm position)(1,2), the turning moment on lateral slopes (1), better hand protection (e.g. when passing through doors)(2,3), life of the rear-wheel ball bearings (2), toe-out, tilt angle, length and width of the base of support (4). Surprisingly the effect of camber on stability has not been reported.

RESEARCH QUESTION

We hypothesized that the static stability of a loaded wheelchair (in the lateral, forward and rear directions), changes as a function of camber.

METHOD

We selected a lightweight wheelchair (an E&J Ultralite Premier) with a diameter of the rear-wheel rim of 55.2 cm, spoked wheels, pneumatic tires and casters. Slight modifications of the back and armrests of the wheelchair were necessary to allow large negative-camber-angle placement. We designed and built camber-adjustment plates to allow a camber range of +15° to -15° at 5° increments.

The wheelchair was occupied by a 95th percentile anthropomorphic test dummy (Hybrid II). Camber was measured using the International Organization for Standardization (ISO) recommendations. The value of camber when measured was slightly different than the built-in value on the camber plate. We expressed the results of stability as a function of measured camber. To measure static stability, we followed ISO methodology (5) using a test plane.

RESULTS

Lateral stability increased from 13.4° to 27.5° as camber varied from +15° to -15° (R^2 = 99.7%)(Fig.1). Forward stability also increased from 22.9° to 30.1° (R^2 = 88.9%) in the same range of camber (Fig.2).

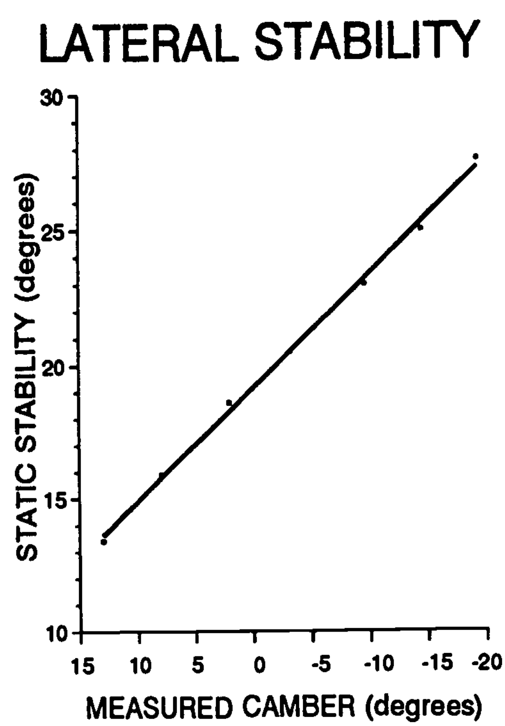

Fig 1. Lateral stability increases as a function of camber

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Conversely, rear stability decreased from 9.5° to 5.8° with the brakes locked (R^2 = 96.5%) and from 15.9° to 10.9° (R^2 = 96.9%) with the brakes unlocked in the range of camber angles studied (Fig.3).

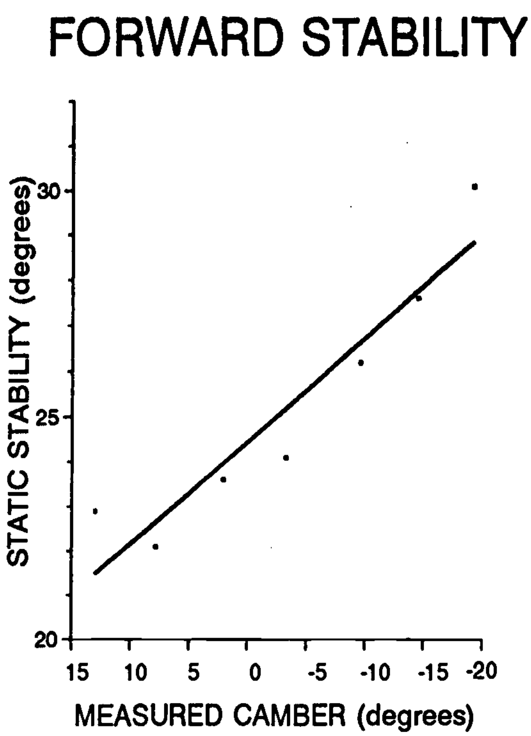

Fig 2 Forward stability increases as a function of camber

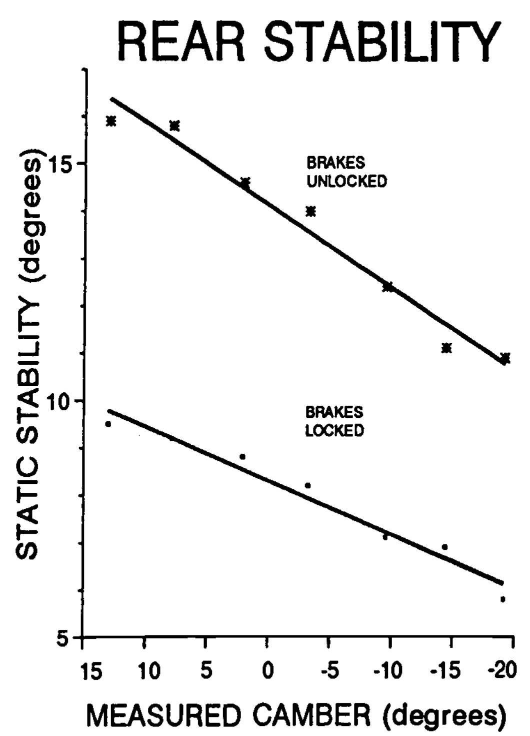

Fig 3. Rear stability decreases as a function of camber

This means that, for each 5° of camber variation, static stability changes by approximately 2.2° in the lateral direction, 1.3° in the forward direction and 0.7 to 0.8° in the backward direction.

DISCUSSION

This study identified the effects of varying rear-wheel camber on the static stability of a loaded wheelchair. We have shown that increasing negative camber increases lateral and forward static stability but that rear stability decreases. The effect on forward and rear stability might be explained by the concomitant displacement of the center of gravity fore-aft and vertically when camber is changed (4).

We suspect that the issues we have identified are generalisable to many other types of cambered wheelchairs. These findings should be taken into consideration when varying the camber on a patient's wheelchair. Other adjustments (e.g. more rigid wheels, vertical displacement of the frame by changing the rear-axle position, changing the frame-to-wheel distance, seat position) could compensate for the rear instability brought with camber change. We hope that these results will lead to better awareness and stimulate research in the field of safety in wheelchairs and specifically the impact of changing camber.

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DETERMINATION OF STATIC STABILITY OF BOWEL CARE-SHOWER CHAIRS

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Abstract

Determination of static stability of five (5) bowel care shower chairs was performed according to ANSI/RESNA WC-01, 1990, with the E&J, Invacare, Lumex, TraumAid and Quickie chairs. The results indicated that the chairs differed significantly with respect to their overall tippiness. The type of load, human or dummy, was not a factor of significance. This finding was in direct opposition to the report by Cooper, Ken, Stewart, and VanSickle (1993) wherein the dummy provided the more conservative measures. The method of tipping, 4 cm bar or sling, was important. The sling method generally provided lower static tipping angles and should be considered the more conservative measure of tippiness. This observations was consistent with that of Cooper *et al.* (1993).

Background

There are over 200,000 persons with spinal cord injuries in the United States today. The majority of these patients have neurogenic bowels, requiring bowel care an average of three times a week. Because bowel care procedures can be lengthy, proper seating posture and comfort is necessary to prevent pressure ulcers. Patient falling is another common problem occurring during transfer, transport, or during actual bowel care or shower. An interdisciplinary research team, comprised of an designer, a nurse, and a human factor/psychologist addressed this problem as part of the VA study : "Toward the design of a new bowel care chair, Pilot Study." The team reported to RESNA 93 the first phase of this study.

Method

Prior to this study the team sought the results of the static stability testing from the whelchair manufacturers. From the inquiries only E&J responded that its chair had not been tested.

Testing equipment: A square testing platform (120 x120 cm) incorporating an electric motor to raise it form 0 to 17 degrees was loaned to the team by Ortho-Kinetics Inc., as well as a 100 kilogram (kg) dummy weight unit. The dummy weight unit was used for the 100 kg test and reconfigured for the 75 kg test (it could not be reconfigured for the 50 kg category). A heavy cloth was used as a flexible sling to secure the wheelchairs for the first series of measures and a 4 cm wooden bar was used to perform the other measurements. Finally a protractor was used to record the progression of the raised platform' angles. Static tip angle was measured when a piece of paper could pass under the front or rear wheels without turning them.

Performing the test: Static tipping angle rearwards, forewards and sidewards was performed with three able-bodied individuals of 100, 75 and 50 Kg respectively, the dummy weight in the 100 and 75 Kg configurations and the five bowel care-shower chairs. The use of the two methods: measuring with the sling and the 4 cm bar provided valuable comparative data.

Results

The static stability test results for each of the five test chairs are presented in Table 1. Measurements were made with human loads of 50, 75, and 100 kg and dummy loads of 75 and 100 kg. Each chair was tipped rearwards, forwards, and sideways using the sling and 4 cm block methods to prevent the chair from slipping. Whenever the chair failed to tip at the equipment limited tip angle of 17 deg, a value of 18 deg was assigned. This practice permitted more powerful statistical analyses to be applied to the data while preserving a conservative treatment effect. The static tip angle was assessed for each chair under the 24 different test configurations: Tip Method (4 cm bar and Sling), Load Type (Human and Dummy), Tip Direction (Rearwards, Forwards, and Sideways), and Weight (75 and 100 kg). Since the 50 kg data were not available for all configurations, these measures were eliminated from the analyses. The purpose of applying these test configurations to each chair was to differentiate performance among chairs; so a repeated measures ANOVA was applied to the data with the test configurations further grouped by "tip method" and "load type". The chairs served as the repeated measure. There were significant differences in "tip method" with the 4cm bar providing a more conservative tip angle (16.9 deg) than the sling method (15.7 deg). There was no difference in the results with respect to "load type", human or dummy. From highest static tipping angle/rank to lowest static tipping angle/rank, the order of the chairs were as follows from most to least stable:

Lumex Invacare E&J Quickie TraumAid

Discussion

The results indicated that the chairs differed significantly with respect to their overall tippiness. The type of load, human or dummy, was not a factor of significance. This finding was in direct opposition to the report by Cooper, Ken, Stewart, and VanSickle (1993) wherein the dum-my provided the more conservative measures. The method of tipping, 4 cm bar or sling, was important. The sling method generally provided lower static tipping angles and should be consi-dered the more conservative measure of tippi-ness. This observations was consistent with that of Cooper *et al.* (1993).

Acknowledgements

Support for this research was provided by the VA Rehabilitation R&D Service as part of the study entitled: Toward the design of a new bowel care-shower chair. The investigators wish to recognize the contribution of Ortho-Kinetics, Inc., for providing the ramp, the Sacred Heart Rehabilitation Hospital and the Spinal Cord Injury Center of the Milwaukee Regional Medical Center for providing the space and chairs used for the study.

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Table 1. Measurements

1. Measurements results with the 40 mm bar

Static tipping angle rearwards

	With dummy weight 50 kg	75 kg	100 kg	With human subjects 50 kg	75 kg	100 kg
E&J		17°+	17°+	17°+	17°	17°
Invacare		17°+	17°+	17°+	17°+	17°+
Lumex		17°+	17°+	17°+	17°+	17°+
TraumAid		17°+	17°+	17°+	17+°	17°+
Quickie		17°+	17°+	17°+	17°+	17°+

Static tipping angle forewards

	With dummy weight 50 kg	75 kg	100 kg	With human subjects 50 kg	75 kg	100 kg
E&J		17°+	17°+	17°+	17°	16°
Invacare		17°+	16°	17°+	17°	14°
Lumex		17°+	17°+	17°+	17°	17°
TraumAid		17°+	17°+	17°+	17°	16°
Quickie		16°	15°	17°+	17°	14°

Static tipping angle sidewards

	With dummy weight 50 kg	75 kg	100 kg	With human subjects 50 kg	75 kg	100 kg
E&J chair		17°+	17°	17°+	16°	15°
Invacare		17°+	17°	17°	17°	17°
Lumex		16°	15°	17°+	17°+	17°+
TraumAid		17°+	17°+	17°	14°	10°
Quickie		17°+	11°+	17°+	17°	14°

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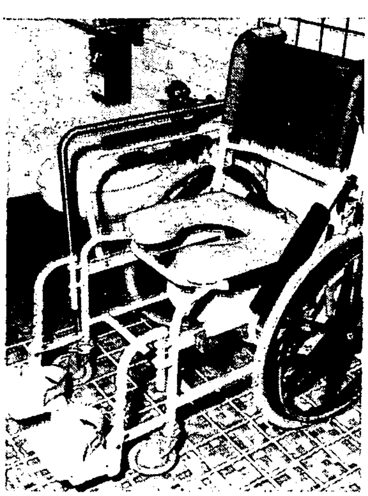
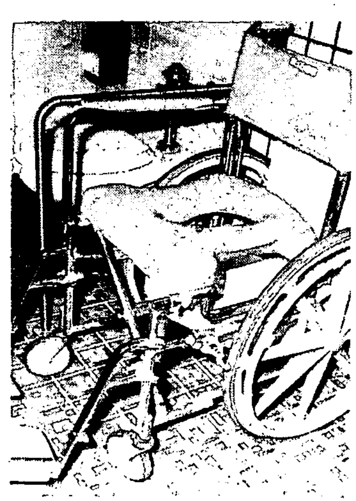
2. Measurements results with the sling

	With dummy weight			With human subjects		
	Static tipping angle rearwards					
	50 kg	75 kg	100 kg	50 kg	75 kg	100 kg
E&J		17°	14°	17°+	15°	14°
Invacare		17°+	17°+	17°+	17°+	17°+
Lumex		17°+	15°	17°+	16°	15°
TraumAid		17°+	14°	17°+	9°	9°
Quickie		17°+	14°	17°	16°	16°
	Static tipping angle forewards					
	50 kg	75 kg	100 kg	50 kg	75 kg	100 kg
E&J		17°	14°	17°+	17°+	17°+
Invacare		16°	16°	17°+	16°	14°
Lumex		17°+	17°+	17°+	16°	15°
TraumAid		17°	13°	17°	15°	15°
Quickie		16°	16°	17°	17°	15°
	Static tipping angle sidewards					
	50 kg	75 kg	100 kg	50 kg	75 kg	100 kg
E&J chair		16°	14°	17°+	17°+	15°
Invacare		15°+	15°	17°+	16°	16°
Lumex		17°+	17°+	17°+	17°+	16°
TraumAid		15°	14°	14°	14°	10°
Quickie		17°	14°	17°+	17°+	15°



Lumex

Invacare



E&J

THE EFFECT OF REACHING AND LEANING ON WHEELCHAIR STABILITY

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ABSTRACT

To test the hypothesis that, when a wheelchair user reaches and leans, the static stability decreases in the direction of the lean and increases in the opposite direction, we studied 21 subjects in a lightweight wheelchair, measuring the forward, rear and lateral static stability on a test plane. Matched-pairs t-tests revealed that reaching and leaning in each of the directions had a significant effect ($p < 0.0001$) on stability, decreasing the stability in the direction of the reach and lean and increasing the stability in the opposite direction. The extent of the difference from the neutral position varied from as little as 9.1% (reaching and leaning back during forward-stability testing) to as much as 124.3% (reaching and leaning forward during rear-stability testing with the brakes locked). Wheelchair users with the ability to control their body position can profoundly affect the stability of their wheelchairs.

BACKGROUND

In an analysis of 2084 nonfatal wheelchair-related accidents reported to the National Electronic Injury Surveillance System Division of the United States Consumer Product Safety Commission (USCPSC) between 1986 and 1990 (1), the most common cause of accidents was tips and falls (73.2%). Tips and falls were also the most common causes of 770 fatal wheelchair-related accidents from the death-certificate database of the USCPSC (2).

A number of studies have shown that the position of the combined center of gravity (CG) of the wheelchair and occupant has an important effect on stability. Experienced wheelchair users with sufficient range, coordination and strength will alter their postures (e.g. leaning forward when going up a slope) to reduce the likelihood of tipping. However, wheelchair users may need to lean to reach an object, inadvertently tipping their chairs over. Surprisingly, the nature and extent of the effect of reaching and leaning on stability has not been reported.

OBJECTIVE

To test the hypothesis that reaching and leaning decreases static stability in the direction of the lean and increases it in the opposite direction, and to determine the extent of this effect.

METHODS

Subjects. We studied 21 able-bodied subjects (11 females and 10 males) with their informed consent.

Wheelchair. Each subject was studied in the same 15.9-kg wheelchair (Invacare Action ST). The rear-wheel diameter was 61 cm and the caster diameter 15 cm. Each of the tires was pneumatic and was inflated to the manufacturer's recommended pressure. The rear-wheel axle was in the highest and most posterior of the available positions, and the chairback upholstery was placed with the upper border at 40 cm above the intersection of the back-support upright and the chair frame. The chair had standard post-type, desk-length armrests, a 5.1-cm-thick foam cushion and a lap belt.

Stability testing. Static stability was measured according to the methods of the International Standards Organization (ISO) (3) on a test plane, the angle of which was measured with a digital inclinometer. The endpoint that defined the limit of stability was liftoff of the uphill wheels from the platform. In a randomly balanced order, we tested forward, lateral and rear (brakes locked and unlocked) stability.

Reaching and leaning

Body position. We tested each subject (in a randomly balanced order) in a neutral position, and while he or she reached and leaned forward, backward and to the side. In the neutral position, the occupant sat upright with the hands grasping the anterior parts of the armrests.

When reaching and leaning forward, the occupant bent forwards at the hips, touching the toes and looking at the feet as if tying his or her shoelaces (i.e. reaching and leaning "toward" a forward tip and "away" from a rear tip).

For lateral stability, the subject reached and leaned sideways as far as possible with the dominant hand over the countertop-height bar while the other hand grasped the ipsilateral armrest. The extent of the reach and lean was limited by the armrest.

When reaching and leaning backwards, each subject placed his or her nondominant hand on an armrest and looked at the dominant hand while reaching and leaning back as far as possible in the midline over a countertop-height bar 78.8 cm above the platform (i.e. "toward" a rear tip and "away" from a forward tip). The extent of the backward reach was limited by the backrest.

Statistical analysis. Comparisons among the three stability values (neutral, toward and away from the expected tip) for each of the four settings (forward, rear-locked, rear-unlocked and lateral stabilities) were made using matched-pairs *t*-tests. To reduce type-1 error, Bonferroni corrections were applied to all *p* values. Statistical significance was defined as $p < 0.05$.

RESULTS

The results of the empirical testing are shown in Figure 1. Reaching forward (i.e. towards a forward tip or away from a rear tip) had a greater effect on stability than reaching back (i.e. away from a forward tip or towards a rear tip). Reaching and leaning away from the tip added stability, with mean increases ranging from 9.1% to 124.3% of the neutral-position values. Reaching and leaning towards the tip reduced stability, with mean decreases ranging from 25.2% to 52.3% of the neutral values. The stability range ("away" minus "toward"), expressed as a percentage of the neutral values, varied from 52.3% to 150.5%. All differences were significant at the $p < 0.0001$ level.

Rear stability was greater without brakes than with the brakes locked -- the mean differences in the neutral, away and toward positions were 8.4 (1.8)°, 16.9 (1.3)°, and 6.1 (2.4)°, respectively ($p < 0.0001$).

DISCUSSION

The results strongly corroborate the hypothesis that reaching and leaning by a wheelchair user decreases stability in the direction of the lean and increases stability in the opposite direction. The magnitude of the effect varied with the direction of the lean. Reaching forward had the greatest effect on stability, presumably due to restrictions in the extent of rear and lateral leaning (due to the backrest and armrest, respectively). The effects of reaching and leaning in the rear and lateral directions would probably be greater if the backrest height was lower or if the armrest was removed.

The expected negative effect on stability of locking the brakes is important in the context of the current study because it suggests that a wheelchair user reaching and leaning backwards would be less likely to tip over if the task was performed with the brakes unlocked than locked -- a conclusion that would not be self-evident to most wheelchair users or to the therapists training them.

Limitations of this study include the use of able-bodied subjects, the use of a single wheelchair and the use of static-stability measures to predict what might happen in a dynamic situation.

Despite these caveats, it can be concluded that wheelchair users with the ability to control their body position can profoundly affect the stability of their wheelchairs, a factor that should be considered in wheelchair design

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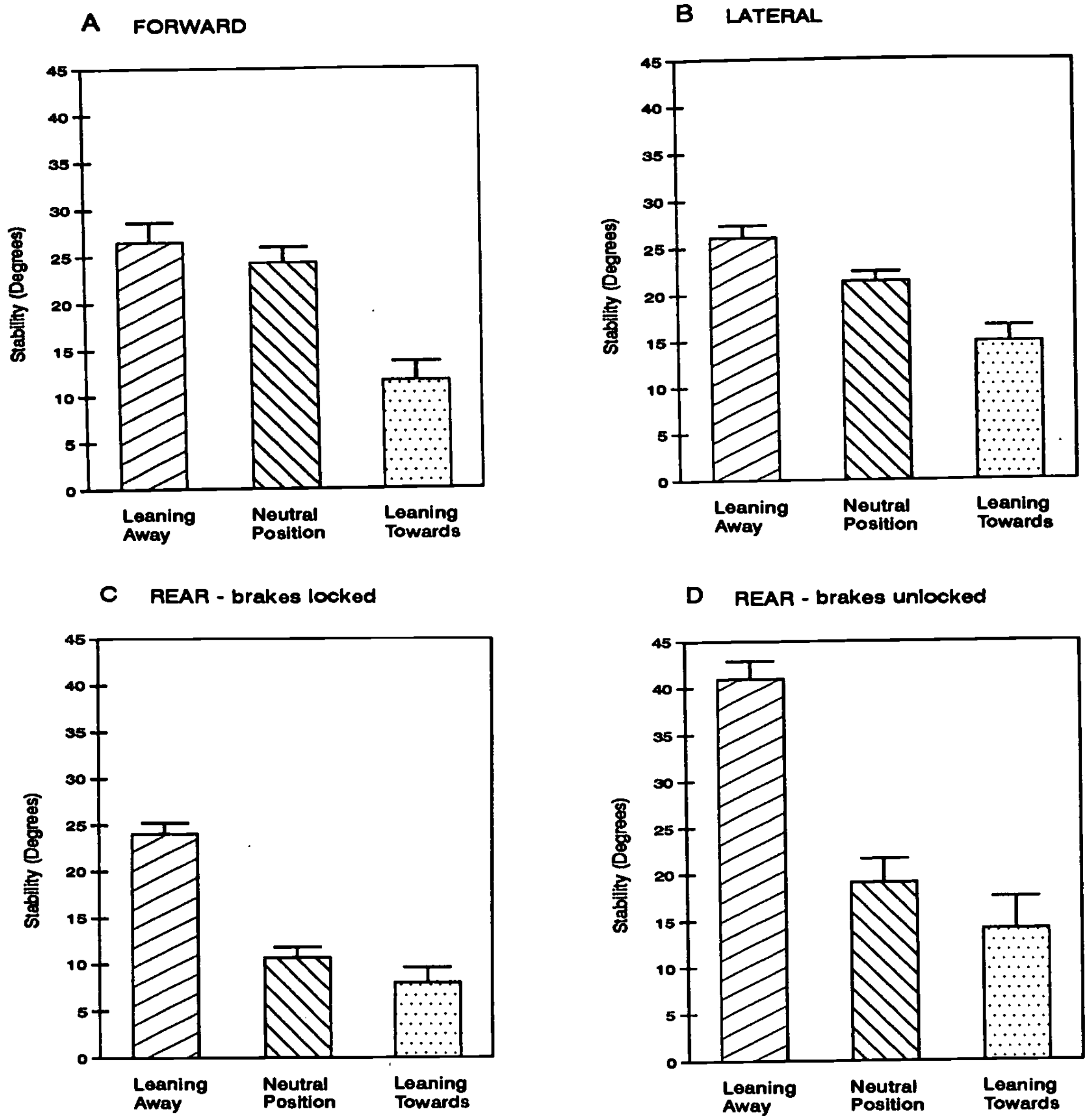
Reaching and leaning



and in the process of wheelchair selection and training.

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MANUAL WHEELCHAIR ISO-ANSI/RESNA FATIGUE TESTING EXPERIENCE

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ABSTRACT

Fatigue testing is used to determine the durability of wheelchairs and their components under a large number of low level stresses that can have a cumulative effect. The purpose of this experiment was to determine the applicability of ANSI/RESNA WC-08 to fatigue testing of manual wheelchairs and to gather some information on the results of manual wheelchairs when using the tests. Nine manual wheelchairs were tested using both a Double-Drum Tester, and Curb-Drop Tester, when appropriate. All tests used a 100 kilogram ANSI/RESNA wheelchair test dummy. A number of wheelchairs did not perform satisfactorily. These standards can be used to assure minimum quality and performance.

Introduction

Fatigue testing is used to determine the durability of wheelchairs and their components under a large number of low level stresses that can have a cumulative effect during the life of the wheelchair, typically three to five years. During fatigue strength testing, wheelchairs must be equipped for normal use, and be thoroughly inspected prior to and after testing. Multiple wheelchairs may be tested; however, all must undergo complete fatigue testing. If wheelchairs have adjustable components, the test engineer must consider the effects of the full range of adjustability. Additional testing is at the discretion of the test engineer.

Double Drum Fatigue Testing Failure can occur in wheelchairs and components due to large numbers of repeated stresses as may occur when riding over small obstacles (e.g., door thresholds, cobblestones, etc.) or over uneven terrain (i.e., those that impart twisting moments).

The ISO-ANSI/RESNA Double-Drum Test is designed to evaluate the durability of a manual wheelchair under dynamic loading. The test requires that the wheelchair be placed on two rollers 250 millimeters in diameter, the front wheels on one roller and the rear wheels on the other roller. Straps of steel 10 millimeters high are bolted to the rollers to simulate bumps, and the rollers are driven at a speed equivalent to 1 m/s. The front roller turns about 5 percent faster than the rear roller so that bumps occur with pseudorandom timing. The test is run until a significant failure occurs or until the number of cycles specified by the manufacturers is exceeded. The greater the number of cycles the wheelchair is able to withstand the more durable it is presumed to be.

Wheelchairs come in a variety of different designs and are constructed from a number of materials. The ISO-ANSI/RESNA Double Drum Test only examines the occurrence of catastrophic failures due to bumps (impulses) at a fixed speed. Different wheelchair designs may react differently to different types of disturbances, and potential failures may go undetected. A double drum tester must be capable of accommodating a wide variety of sizes and types of wheelchairs.

Curb Drop Testing It is not uncommon for wheelchair users to propel their wheelchairs off of curbs, which when repeated can result in structural failure. This test was designed to simulate conditions which occur when a wheelchair and occupant free-fall from a height of 50 millimeters in a normal attitude.

Any apparatus which provides free-fall for the wheelchair and dummy to a solid flat surface is acceptable. The wheelchair must start its fall from horizontal and be free to rotate. The wheels must rotate to prevent creating flat spots and unrealistic loading of the wheelchair.

The wheelchair is loaded with an appropriate fatigue test dummy (50, 75 or 100 kilogram) for 1/30 of the number of cycles specified for the double drum tester.

Research Question The purpose of this experiment was to determine the applicability of ISO 7176 part 8, and ANSI/RESNA WC-08 to fatigue testing of manual wheelchairs. A secondary component of this study was to gather some information on the results of various manual wheelchairs when using the double-drum and curb-drop tests.

Methods

Nine manual wheelchairs were tested using both an ISO-ANSI/RESNA Double-Drum Tester, and Curb-Drop Tester when appropriate. All wheelchairs were tested using a 100 kilogram ANSI/RESNA wheelchair test dummy.

Equipment Each wheelchair was placed on top of four rollers: the rollers for the front wheels share a common shaft, as do the rollers for the rear wheels. The front wheels rotate 5% faster than the rear wheels so that over a complete testing cycle the wheelchair doess not always receive the bump at the same time. This helps to excite more modes of the wheelchair, and to minimize creating flat spots on the wheels. Each wheel rides on a separate roller that can turn either eccentrically or concentrically about its axle. Using four separate rollers, one for each wheel, ensures that the magnitude of the undulations remains constant during testing if the wheelchair moves laterally. The double-drum tester is controlled and continuously monitored by a DOS compatible Intel 8088 based computer.

The curb drop tester used in this study lifts the wheelchair and dummy by cables attached to the dummy on one end and a carriage at the other. The chair is lifted as the carriage rises and then drops as the carriage is propelled downward with springs. The wheelchair and dummy are free to rotate as they fall, allowing for a more natural motion. The curb drop tester is controlled by a DOS compatible Intel 8088 based computer. The status of the machine and key components is monitored continuously by the computer.

Protocol All adjustable components on the wheelchair were set to the manufacturer's specifications. Each wheelchair was loaded with a 100 kilogram dummy. Foam coverings on the seat and backrest surfaces of the dummy were replaced prior to each test. The dummy was seated as called for in ISO 7176-08. All tires were maintained at proper inflation pressure. Each wheelchair was retained on the Double-Drum Tester by two tie-rods attached to the wheelchair at the rear axles.

Each wheelchair was first placed on the Double-Drum Tester for the number of cycles specified by the manufacturer. If the wheelchair withstood the number of cycles specified on the Double-Drum Tester, it was placed on the Curb-Drop Tester for 1/30 the number of drops as cycles performed on the Double-Drum Tester (i.e., if the wheelchair performed 100,000 cycles on the Double-Drum Tester, it was tested for 3334 drops). Testing was terminated if the wheelchair withstood the specified number of cycles or failed.

Failure Criteria Three classes of failures were used during this study. Class 1 failures were used to denote minor adjustments that could be performed by the user, or someone knowledgeable with tools. Class 2 failures would require replacement parts and would normally be performed by a dealer or repair service. Class 3 failures refers to major structural damage or breakage of a key component (e.g., axle, caster spindle).

Results

Results from fatigue testing of several wheelchairs on ISO double drum (Table 1) and curb drop testers (Table 2) using a 100 kilogram dummy. Our results demonstrate that wheelchairs respond differently, even those from the same manufacturer, indicating the need for independent testing and for applying this information to wheelchair design.

Table 1 Fatigue Test Results for Manual Wheelchairs Tested with a Double-Drum Tester.

Cycles	Comments
CHAIR 1	
20133	Front caster alignment was adjusted. Casters had moved in excess of 15 degrees.
20186	Left front caster spindle failed. Right front caster fell off upon removal from machine.
CHAIR 2	
129,688	No apparent damage to wheelchair or components.
CHAIR 3	
35,000	Cross (X) brace noticeably bent. The member extending from the upper right to the lower left of the chair was distorted by about one inch from end to the other. The other cross brace was distorted about 1/4 inch.
42,600	Catastrophic failure occurred. The frame distortion led to overloading the right front castor. The right front castor subsequently failed. Both the rim and the tire were destroyed in this failure. The frame in the area of the right front castor was also severely distorted. The frame cracked at the intersection of the backrest vertical and horizontal member. The crack was presumably caused by a combination of the oscillating load from the dummy and the previous distortion of the frame in other areas. The cross members which make up the x-brace were further bent. The worst case being 1.5 inches of deflection from end to end. The vertical support member of the footrests was bent about 1/2 inch from top to bottom.
CHAIR 4	
30,991	The pushrim on the right wheel became detached from the wheels due to vibration. All of the screws which hold the pushrim in place had disengaged. The left wheel pushrim was in similar condition, but the screws had only loosened. The left side of the frame had numerous cracks which included the complete severing of one section of the frame used in the folding mechanism. The right side of the frame also exhibited several cracks. The backrests failed at their intersection with the frame. The lower side frame members failed where they intersect with the cross-brace members. The failures caused complete separation on the left side. On the right side the back rest failure caused complete separation. The cross members of the frame were found to be bent. The deviation was approximately 1.5 inches from end to end. Some of the deflection was initiated during static impact testing, but was amplified during fatigue testing.
CHAIR 5	
50,260	Left caster bearings failed. This caused the left front fork to pull out of the castor housing. The chair then rotated forward on the two-drum tester. Further frame damage was caused by forward rotation.
CHAIR 6	
38,682	Indications are that the cross-brace on the right side failed as did the seat back. These failures led to numerous other structural failures.
CHAIR 7	
60,605	Rear pair of seat screws broke and were replaced at 13624, 22482 and 32797 cycles. Both footrests failed. Obvious structural failure to footrest. Frame cracked at footrest attachment points.
CHAIR 8	
100,000	Bearings in the front castor housings were damaged. Swivel resistance was drastically increased, and one or more bearings were flattened to yield an indexing effect.
CHAIR 9	
100,000	Bearings in the front castor housings were damaged. Swivel resistance was drastically

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increased, and one or more bearings were flattened to yield an indexing effect. Castor housings were no longer perpendicular to rolling surface (right displaced 4 degrees, left displaced 1 degree).

Those wheelchairs which satisfactorily completed the specified number of cycles on the Double-Drum Tester were placed on the Curb-Drop Tester. The results of Curb-Drop testing are presented in Table 2.

Table 2 Fatigue Test Results for Manual Wheelchairs Tested with a Curb-Drop Tester.

Cycles	Comments
CHAIR 2	
554	Right front castor came loose and was adjusted.
1864	Left rear wheel not turning freely.
3238	Rear wheels showed signs of splaying.
4232	Test completed.
CHAIR 8	
3500	Significant splaying developed in rear wheels, about 3/4" from top of armrests to lowest point on frame. Approximately, 1/2" of toe-out developed in rear wheels. There was a weld fracture on the right hinge of the folding mechanism (fracture was between top of the hinge member and the main frame).
CHAIR 9	
3500	Significant splaying developed in rear wheels, about 1/4" from top of armrests to lowest point on frame. Approximately, 1/2" of toe-out developed in rear wheels. Beam attached to footrest was bent down about 1/2 inch.

Discussion

A number of wheelchairs did not perform satisfactorily during these tests. The wheelchairs tested ranged in price from a few hundred dollars to nearly $3000. The cost of the wheelchair was not a good indicator of fatigue life. Some of the least expensive wheelchairs performed best. Most of the wheelchairs tested have been offered for sale for several years, and undoubtedly there are a number of them in use. We have no data to indicate failures of these products when in use by consumers. This should not be interpreted to mean these failures do not occur, only that we made no attempt to correlate failures in use with failures during testing. We did discover that fatigue life can be improved by using larger diameter casters. Pneumatic casters and drive wheel tires can also improve fatigue life.

Wheelchair testing must become a significant component of wheelchair design and manufacturer. ISO and ANSI/RESNA standards have been developed over many years by dedicated people from academia, industry, government, and consumer groups. These standards can be used to assure minimum quality and performance. Currently three major loop holes exist in the standards process: many companies do not test to the standards, only one wheelchair needs to be tested allowing companies to test and retest until one wheelchair passes, and there is little or no independent validation of test results.

Conclusion

The high number of wheelchairs which performed poorly on these tests is alarming. Some of the wheelchairs tested were from smaller manufacturers who likely do not have extensive in-house test facilities. Others were from companies which sell large numbers of units. These results suggest that wheelchairs need to be evaluated by independent test laboratories prior to being released to the market. Government agencies, and large purchasers should insist upon periodic independent testing for quality control. Consumers and prescribers should insist upon only tested and approved products for themselves and their clients. We recommend that ANSI/RESNA begin a process whereby test facilities are certified to perform wheelchair standards testing, and that stickers indicating compliance with ANSI/RESNA standards be applied to passing wheelchair models. Moreover, we recommend that three standard production quality wheelchairs be required for testing with the ANSI/RESNA fatigue test methods. The lowest acceptable value should be 100,000 cylces on the Double-Drum Tester for depot wheelchairs, and 200,000 for rehabilitation type wheelchairs. All three test wheelchairs must exceed the appropriate value.

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THE UVA/MR MAINTENANCE-FREE WHEELCHAIR TIRE

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ABSTRACT

The performance characteristics of a patented maintenance-free rubber wheelchair tire prototype were investigated in comparison with a typical pneumatic wheelchair tire. The tests involved measuring the rolling resistance, wear, coefficient of friction, and spring constant of the tire. The new tires performed in a similar manner to typical pneumatic tires, but with much improved life due to its superior rubber formulation and maintenance-free design. The results of the testing will be used to improve the tire characteristics.

INTRODUCTION

Airless, solid rubber, wheelchair tires offer maintenance and wear advantages over pneumatic tires, but commercially available models do not give as comfortable a ride. Wheelchair users surveyed say that pneumatic tires are the largest repair problem [Ref. 1] for them. As such, the pneumatic tire is a greater inhibitor of independent living than any other problem with wheelchairs.

A new, patented [2], maintenance-free rubber tire which is nonpneumatic and offers much improved characteristics over available models has been under development since 1988. Currently, a commercial version of the tire is available in the U.K., but the tire is still under development in the USA. This paper will present some of the test results for the sample tires that have been manufactured in the USA, and discuss the plans for further commercial development.

TIRE PERFORMANCE CHARACTERISTICS

In the following sections the results of tests on the UVa/MR prototype tires manufactured in the USA are presented.

ROLLING RESISTANCE

The rolling resistance of the UVa/MR tire and a 60 psi pneumatic tire were measured on a treadmill at various speeds and loads. Test results showed that speed was not a factor for typical wheelchair speeds, but rolling resistance for a pair of 24 inch tires varied linearly with load, as given in Fig. 1. This data shows that the UVa/MR tire has a 20% higher rolling resistance. Pneumatic tires have a very low rolling resistance, especially high pressure tires. The hysteresis of the rubber is the main contributor to rolling resistance on a hard flat surface, and air has no hysteresis. The UVa/MR tire was designed to optimize a number of desirable characteristics, and rubber hysteresis can be optimized but at the expense of other properties such as wear.

WEAR

The wear testing was done on bicycle versions of the UVa/MR tire in order to simplify and accelerate the testing. Testing under similar loading conditions would be expected to give similar results for the UVa/MR tire and pneumatic tires that are manufactured from rubber with the same wear characteristics. Testing shows that a good black pneumatic bicycle tire has similar wear characteristics, but a typical gray rubber pneumatic tire has inferior wear characteristics, on the order of 1/3.5 of the value of the good black tire [3]. The very good wear properties of the UVa/MR tire are due to the superior formulation of rubber used in manufacture of the tire.

The experimental program with the bicycle tires at a load of about 100 lbs per wheel gave a wear factor for the depth of the worn tread on the order of 3000 miles/mm on concrete. At a typical wheelchair load per tire of 60 lbs the wear factor should improve linearly giving an estimated value of 5,000 miles/mm, as shown on Fig. 2. A gray 60 psi pneumatic would have a poor wear factor on the order of 1,400 miles/mm, as also shown on Fig. 2. An additional study was carried out with the bicycle for a long distance bike ride across Canada. The trip was 4,000 miles under an extreme load of rider and camping gear, averaging 200 lbs on the rear wheel. At an expected wear factor of 1,500 mi/mm it was predicted that the tire would wear about 2.7 mm, and this was the approximate result determined after the trip. The most important aspect of the cross Canada trip is that the UVa/MR tire never "got a puncture," but other riders encountered on the trip did have punctures with their pneumatic tires.

COEFFICIENT OF FRICTION

The dynamic coefficient of friction for the tires was measured under several typical loads with the tire mounted on a 24 inch rim and using a spring scale to determine the force required to slide the tire on each surface tested. The results are plotted in Fig. 3. The data show that the UVa/MR tire has a coefficient of friction similar to a black bicycle tire but considerably better than a 60 psi gray rubber pneumatic wheelchair tire.

RADIAL SPRING CONSTANT

The radial spring constant of the tire is an indicator of the ride quality. If the spring constant is low the ride quality has been found to be "comfortable" for wheelchair users [3]. A typical 60 psi gray pneumatic wheelchair tire has a spring constant of k=675 lbs/in which is independent of load. The test to evaluate spring constant involves measuring the load and deflection of the tire and calculating the spring constant as load per unit deflection. Fig. 4 shows the load-deflection curve for the UVa/MR tire where it can be seen that the curve is not linear. With the tire under a normal static load of 60 lbs the radial spring constant is k=960 lbs/inch; which is 42% higher than for a 60 psi pneumatic wheelchair tire. The geometric design of the tire allows for an adjustment in the radial spring constant, and new tires will be modified so that the radial spring constant is more nearly the same as a 60 psi pneumatic tire.

DISCUSSION

The new UVa/MR maintenance-free tire prototype is well within design requirements for application to wheelchairs. Practical experience and test results show that the tire has a considerably improved life over pneumatic tires used for wheelchairs, and would be classed as a wheelchair lifetime tire. The good wear performance comes at a cost for the improved quality of the rubber formulation, but over the long term life of the tire it is expected that the UVa/MR tire will be very cost effective. Using the performance of a 60 psi gray pneumatic wheelchair tire as a standard, the prototype can still be improved, and it is planned to accomplish this with the next set of prototype tires.

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Fig. 1 Rolling Resistance @ 2 mph

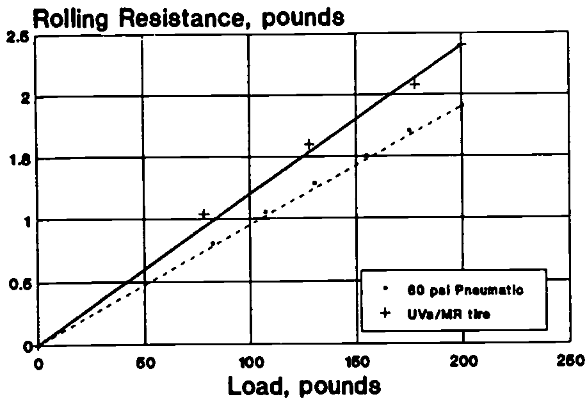


Fig 3 Coefficient of Friction
Smooth Concrete Surface

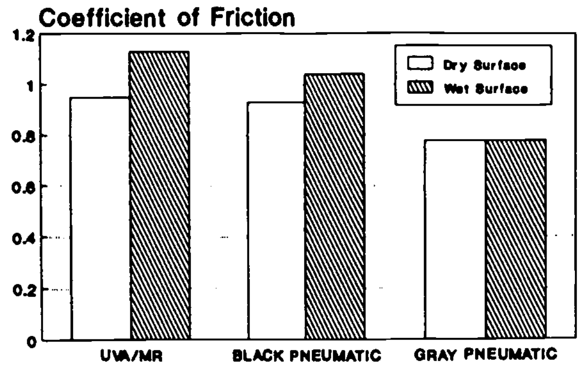


Fig. 2 Tire Wear on Concrete
60 lbs Load per Tire

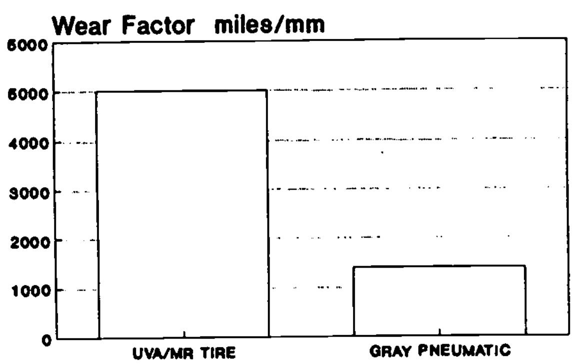
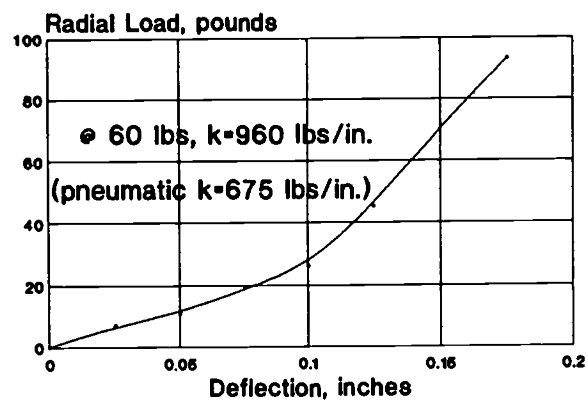


Fig. 4 Load vs. Deflection



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PORTABLE HEAD SUPPORT

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Abstract

When problems with head positioning are encountered, it is generally in individuals who must use a wheelchair for positioning and mobility. Typically proper head postioning can be accomplished in these cases through the use of commercially available products which are attached to the wheelchair backrest. The challenge in this case is to provide head support to someone who is not a wheelchair user, and therefore uses a variety of chairs and work surfaces.

Background

Mary is a 71 year old ambulatory woman with a diagnosis of amyotrophic lateral sclerosis (ALS) with primarily bulbar involvement. Since the onset of her symptoms, she has experienced progressive weakness of her oral motor and cervical musculature. As a result of this weakness Mary has no oral communication and also has difficulty maintaining an upright head position. This is problematic because her current means of communicating is through the use of a Magic Slate, pencil and paper or a TDD. When she flexes her neck to write or look down she often does not have sufficient strength to extend her neck and bring her head back up. This results in her manually positioning her head with her arm which interferes with her ability to free her upper extremities for ADL task performance (see Figure #1).

Objective

Mary's involvement with Rehab Technology Services (UMRTS) at the University of Michigan began on

Figure #1

9/17/92 after consulting her physician for head and neck positioning. She was looking for an assistive device that would position her head and free up both arms. She not only wanted it to be supportive but also comfortable and aesthetically pleasing.

Method

Before her involvement with UMRTS, she had tried several commercially available products, primarily cervical collars fabricated from various materials. These were ineffective as they were either too soft and did not provide enough support, or they were too firm and caused discomfort. The firmer cervical collars provided her with adequate support but applied too much pressure along her mandible which occluded her molars and caused TMJ like symptoms. She also did not like the fact that they were attached to her. Mary explained all of this during the initial evaluation, where it was decided that the primary goal was to provide her with a head positioning device that:

1. did not put pressure on the lower mandible.
2. was adaptable to different settings.

Head Support

3. was preferably not attached to her.
4. allowed a limited range of head movement that she could actively move within.
5. was adjustable to physical changes.
6. looked good.

The following solutions were considered:
1. A cervical collar with cutouts.
2. A portable back/headrest with a head strap.
3. A forehead pad on a multi-adjustable arm that would mount to a variety of surfaces.
4. A portable back/headrest with a forehead pad.

The above solutions were simulated by using various materials or stock items with the following findings:
- The first solution was excluded as Mary felt that it would still cause too much pressure and she was also resistant to having something attached to her.
- The second option was not appropriate because it did not allow her freedom to change her head position, the strap applied too much pressure to her forehead, and/or it migrated up her forehead to where it was no longer supportive.
- The third alternative required too much adjustment, mounting a forehead pad to a variety of surfaces also allowed too much room for error in obtaining the correct positioning.
- The fourth solution was chosen since it met the criterion established by Mary and the rehab team.

Results

A portable back/headrest with a forehead pad was then designed and constructed at RTS. It was made using an Obus Forme back support, Otto Bock small C headrest on a multi-adjustable mount, and a custom forehead pad. The pad itself was contoured to Mary's forehead and placed on a swing-away mount that was attached to the headrest (see Figure #2). Mary demonstrated

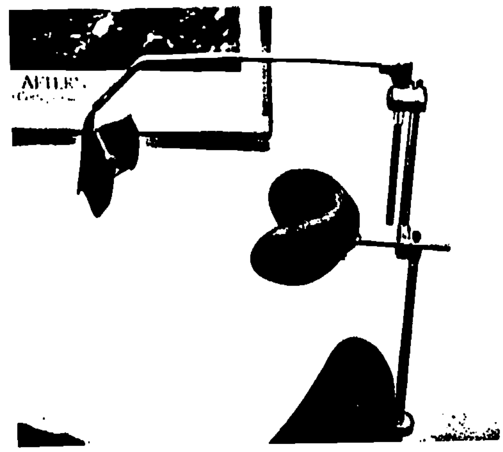

Figure #2

independence with swinging the forehead pad out of the way for transfers and in place for support. The neck and forehead portion of the device was made multi-adjustable to obtain the optimal position for varying conditions. The device was positioned by centering it in relation to the chair's backrest and rested on the chair seat. It was secured to the chair with velcro straps versus the elastic strap provided by the manufacturer.

Conclusions

Mary was given a trial period of two weeks to determine whether or not the back/headrest would work in her home environment. During this trial period two problems emerged. The proximal portion of the headrest was applying too much pressure to the back of her neck. This was adjusted through the headrest hardware by raising the headrest and adjusting the angle of the headpad. The second problem occurred when the Obus Forme slid down below the top portion of the seat on one of her chairs due to a large gap at the back of the seat. This caused the back/headrest to be incorrectly positioned. This was resolved by filling the gap with ethafoam blocks so the Obus Forme could rest at the level of the seat.

Head Support

At the time this paper was written, Mary used this device daily because it gave her greater independence with her ADL's. It allowed her to use both of her hands while performing a task, whereas before she always had to support her head with one of her hands. She continued to be followed by the rehab team at UMRTS and had one minor adjustment since the final delivery (see Figure #3).

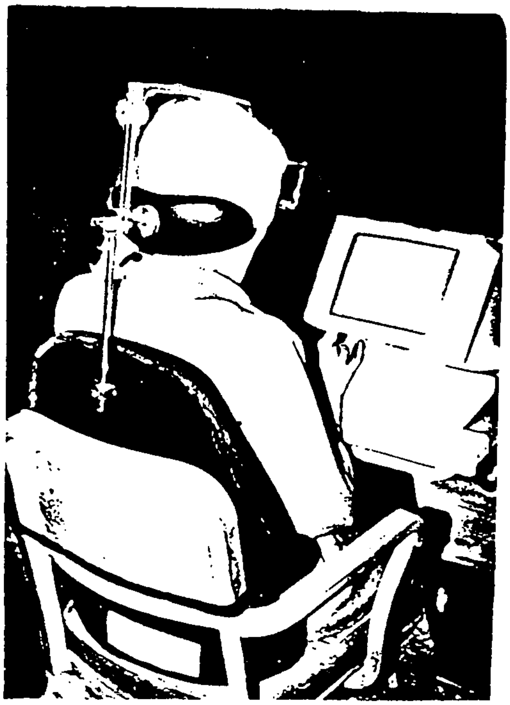

Figure #3

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THREE CUSTOM ADAPTATIONS FOR A CHILD WITH SEGMENTAL DYSTONIA

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ABSTRACT

In providing assistive technology to a pediatric population, rarely does a single seating system and mobility base meet all the needs of a client and her family. Frequently, clinicians have a limited view of how and in what situations assistive technology is utilized or even necessary. Including the family on the interdisciplinary team insures that all issues and environments will be addressed to allow provision of the most appropriate assistive devices. This case study describes a young girl with segmental dystonia and the three pieces of equipment that have been customized to maximize her comfort, safety, independence, and participation in family activities.

BACKGROUND

Indra is a delightful 10 year old girl with a diagnosis of segmental dystonia. She demonstrates wide fluctuations in muscle tone characterized by a hypotonic trunk and hypertonic lower extremities. Indra's upper extremities display ballistic movements which require positioning of her arms in some type of restraint for protection and function. Indra lacks functional use of her upper extremities. Conversely, when well positioned, she demonstrates good control of her lower extremities and even some fine motor dexterity with her feet and toes. Indra ambulates with a Mulholland Walkabout walker which controls her trunk and upper extremities. She is also able to foot propel a manual wheelchair. Due to her extremely variable volitional control, Indra's seated positioning is critical to insure her comfort, safety, and functional ability.

Indra's mother initiated referrals to this assistive technology service requesting modifications to several pieces of equipment. Indra had grown significantly, and was no longer safely positioned in her devices. She had recently received a new Quickie II manual wheelchair and a new Columbia car seat from an outside vendor. As delivered,

Indra—ready to roll in her MWC

Indra was unable to reach the floor for foot propulsion in the new MWC. In addition, the commercial seating system consisting of a Jay seat and sling back upholstery, did not provide the lateral support and upper extremity control necessary for Indra's safety, comfort, and function. The Columbia car seat, while appropriate for Indra's height increase, was too wide to properly maintain a good midline sitting position.

OBJECTIVE

The main goals of our intervention were to improve positioning and safety in both her Quickie II MWC and her Columbia car seat and to maximize her functional mobility by foot propulsion in her Quickie II MWC. As our work proceeded, Indra's mother introduced a third equipment need.

Three Custom Adaptations

In the past, Indra had enjoyed bicycling with her family by riding in a Cannondale Bugger trailer. While her weight was still well within the allowable limits of the bike trailer, Indra's growth in length caused her feet to dangle dangerously outside of the trailer. The simple shoulder harness and seat belt system designed for able-bodied passengers was not sufficient to safely maintain Indra's seated position in the trailer. Our third project goal was to allow Indra to continue to participate in family bicycle outings by modifying the Cannondale Bugger trailer.

APPROACH

This assistive technology service relies on an interdisciplinary team approach which emphasizes family involvement and input from school and clinic based professionals. Upon initial assessment, the team prioritized modifications to Indra's Columbia car seat and Quickie II MWC. The car seat adaptations emphasized provision of support for safety and stability. Modifications to her Quickie II MWC incorporated some of the seating concepts employed in the car seat but focused on lower extremity freedom of movement for function. Modifications to the Bugger were completed last and utilized the Columbia car seat as an independent positioning system mounted into the modified bike trailer. A key guiding factor was to design equipment that could adequately control Indra's extraneous movements but not obscure the person within the equipment.

Columbia Car Seat

Indra's car seat lacked both the lateral supports and upper extremity and head control that Indra required to maintain a safe upright posture when traveling in the car. A custom foam insert was designed to provide more control at the pelvis and to provide the necessary lateral support. The shoulder harness was lengthened and padded to improve comfort. A unique headrest providing occipital support as well as lateral control was incorporated into the system using a fixed position, growth-adjustable mounting system. As with all work from our program, Indra and her family had the opportunity to trial the equipment and make further adjustments to improve her comfort and stability. The structural integrity of the car seat shell was not altered in any way by the positioning modifications.

Quickie II MWC

The provision of a standard MWC with a Jay seat and sling back was clearly not appropriate for the very unique needs of this client. In order to improve Indra's overall positioning and maximize her functional independence we implemented changes in the commercial components in addition to our custom fabrication.

Modifications included replacing the 22" wheels and 8" front casters with 20" wheels and 5" casters. The seat upholstery was removed and replaced by a custom pan which dropped between the rails to further lower overall seat-to-floor height. The focus on mobility led to the design of

Headrest detail in her carseat

widely flared adductors incorporated into the seat pan, which provided the necessary control at the hips, but still allowed for freedom of movement. The team carefully observed and discussed Indra's use of her lower extremities when propelling her MWC. This led to the design of a slightly shallow seat depth which did not adversely affect Indra's comfort or overall positioning. The front swing-

Time to hit the road

away rigging was removed to increase clearance and freedom of movement for Indra's legs. This change necessitated design of an alternative footrest for use when Indra was pushed in her MWC. Indra and her mother suggested a simple webbing strap spanning the front of the frame. A custom linear back with laterals, custom butterfly trunk support, and custom armtroughs with padded straps were fabricated to maintain good overall seated position and to safely maintain Indra's arms.

Indra and her family had an extensive opportunity to trial the equipment prior to final upholstery. This was clearly critical in the design of Indra's headrest. The headrest's unique shape was taken from the successful design used in her car seat. Indra experimented with the headrest in all her usual settings, including school, transportation, and home. Input from staff at school, Indra, and her mom guided careful progressive modifications to maximize support and control but minimize visual obstruction.

Cannondale Bugger Bicycle Trailer

This final project proved to be a challenge for the assistive technology team. We needed to modify the trailer such that Indra would remain safely positioned while riding in the trailer. We chose to incorporate the Columbia car seat as the positioning device, since Indra was well protected and quite comfortable in her car seat. We designed a quick release mounting system that attached the car seat to the bike trailer. Our only outstanding problem was where to put Indra's feet which protruded dangerously out the back of the trailer. Our solution was to cut out a portion of the trailer shell and add in a custom molded kydex foot bucket which extended the overall depth of the system without compromising ground clearance.

DISCUSSION

Indra is functional and independent in her Quickie II MWC. She continues to use her Columbia car seat for family travel. Road tests of the Bugger bicycle trailer will wait until the spring but preliminary indoor trials yielded promising results. The success of our intervention with Indra is based upon teamwork and an appropriate combination of commercial components and custom fabrication. The three projects presented, while each quite unique, rely heavily on the information learned from prior work. Assistive technology has a tremendous impact on Indra's daily activities because she has the right customized equipment for each situation.

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A WHEELCHAIR-MOUNTED INFANT CARE SEAT

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ABSTRACT

An infant care seat was designed which allows a wheelchair-riding parent with limited hand and arm strength to better interact with her or his infant child. The seat mounts easily on a power wheelchair. With little effort, it can be moved sideways, in and out, and rotated in a horizontal plane in relation to the parent. It has a readily-adjustable seat-to-back angle, can be locked safely in place, and has a rocking feature. It can be retrofitted with a larger seat as the child grows. Use of this prototype seat by a mother with spinal muscular atrophy was a major contributor to her ability to independently perform many parenting tasks as well as enjoy the company of her infant son.

BACKGROUND

An increasing number of people with disabilities are having children and are facing the challenges of parenthood. Through the Looking Glass, an agency which specializes in research, training and resources serving parents with disabilities, has a grant from NIDRR (US Department of Education) entitled, "Developing Adaptive Equipment and Techniques for Physically Disabled Parents and their Babies within the Context of Psychosocial Services." This project is demonstrating how to blend technology with infant mental health/ family support services, and includes the adaptation and development of specialized baby care equipment.

Most of the designs and ideas for adaptive baby-care equipment available in published form are oriented towards paraplegic wheelchair riders. When a parent has a disability which also involves limited use of her or his upper extremities, the need for additional tools and modifications to the environment is even greater. Staff at Through the Looking Glass requested that the author design an infant seating device which would allow parents with quadriplegia increased opportunities for close interaction with their babies and enable them to independently perform more parenting tasks.

METHOD

The following general design criteria were initially established for the project:

A) The equipment will be designed for the use of a person with a disability similar to that of a spinal chord injury at the C-6,7 level—with an eye toward serving those with a higher level of disability as well.

B) Initial designs will focus on accommodating an infant from birth to six months—with a perspective of easily upgrading some equipment for larger sizes as needed.

C) The activities to be promoted include transporting, feeding, dressing/diapering, cleaning, playing and general intimate interaction.

D) The device should be as adjustable as possible to accommodate the user's available functioning and as "transparent" as possible to minimize the barriers between the infant and her or his parent and environment.

E) The final product should be relatively easy to duplicate, either in one workshop, or through the sharing of detailed drawings and specifications.

Parent-baby interactions were studied informally through videotapes of disabled parents which had been archived by Through the Looking Glass and by direct observation of parenting by non-disabled friends with babies. Discussions were held with TLG staff and other Occupational Therapists about the challenges of parent-infant interaction. In addition, visits were paid to children's furniture stores, examining and measuring different seats and approaches to support, safety, seat tilt, and seat-to-back angles.

Although the initial conception was to design and construct an infant seat which would be tested by several volunteers, a new situation developed early on in the project after a parent with a newborn child contacted TLG for assistance. She has spinal muscular atrophy, rides a power wheelchair, and has limited strength in her upper extremities, with some gross motor and almost no fine motor control in her hands. This presented a very specific context for the equipment being working on, together with a consumer who could be more actively involved in the design process. The final product was tailored to this parent's needs and specifications—including her body size, type of her wheelchair, etc.—while remaining broadly applicable to a wider range of parents with disabilities.

DESIGN SOLUTION

The design of the infant care seat involved the solution of a number of challenges relating to the interrelated components of the seat system. Selected features will be described.

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Seat Frame

One of the biggest challenges was to design a seat which would allow the parent to come as close to the infant child as possible while providing comfort and security. This required the minimizing of all dimensions. A decision was made to utilize a fabric seat suspended on a padded 1/4" steel rod frame, thereby eliminating thick, hard sides. It was designed to be modular to accept longer seat and back sections to accommodate the growth of the child.

Seat Covering

The seat frame is covered in a fabric used for baby quilts. It is held together with snaps and removes easily for cleaning. A triangular restraining belt is sewn into the seat to secure the infant. One corner is sewn in at the crotch location while the other two are attachable by velcro to the sides of the seat frame at the child's waist level. Large loops are sewn into the velcro-covered ends of the restraint to enable the mother to manipulate them.

Adjustable seat-to-back angle

The adjustable pivot mechanism was the most critical element to the whole seat design. After numerous attempts, a cogged wheel and pawl concept was settled on. The prototype is built around a modified 7/8" ratcheting box wrench which is small in overall diameter yet provides seven stops over 90° of rotation. One of these assemblies is provided for each side of the seat frame, with the cogged wheels being fixed to the seat supports.

Operation: When the back frame is lifted up from horizontal towards the vertical, the wrench body, to which the pawl is attached, rotates around the fixed wheel, ratcheting. When released, the back is preventing from moving downward by the action of the pawl fitting into the notches on the cogged wheel.

In order for the back to return towards a horizontal position, the pawl must be disengaged from notches in the wheel. This is done by means of a pivoting release arm attached across and behind the top of the seat frame. Thin strong lines are wrapped around each end of this release arm and are run through tubular sides of the seat frame to a tab on each pawl. As the arm pivots upward, the lines tighten and pull on the pawls. However, the seat back must be lifted up slightly to relieve the tension before the pawls will pull away from the cogged wheels. This ensures that the child's weight is supported safely before the seat back is allowed to drop down. The release arm is designed to be easy to manipulate without any fine motor activity.

Rocking Mechanism

A back and forth rocking movement is built in by attaching the seat frame to the seat enclosure by means of parallel bars—similar to a stationary rocking chair. A simple rotating latch with a large wooden handle provides the parent with the ability to fix the seat in place or allow it to rock.

Horizontal Motion

The provision of a wide range of horizontal motion—lateral, proximal-distal, and rotational—is based on sliding between two flat, low-friction surfaces. The foundation is a stationary plywood sub-base from which a steel pedestal projects upward. The pedestal column is approximately 2" in diameter and 1.5" high. On top of the pedestal is fixed a round steel plate, 7.5" in diameter, covered with UHMW polyethylene plastic. The bottom of the seat enclosure rests upon this

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plate and can slide about freely over the pedestal. It is laminated with textured ABS to reduce friction. The two sliding surfaces are kept together by enclosure sides which extend down and wrap under the pedestal disk, sandwiching it between two layers of the enclosure base. The edges wrap around only enough to prevent the disk from being able to separate from the base. This allows for maximum seat travel in relation to the pedestal column (7.5" laterally, 3.5" in-out, 360° rotation). The occupied seat can be easily moved with a pushing or pulling motion yet has enough friction to tend to stay in place.

Safety Lock
The option of locking the seat in a fixed position is provided. There is a hole through the center of the pedestal and disk through which a piston of approximately 1" diameter can move freely up or down. The top of the piston is covered with a non-slip rubber surface. A steel rod onto which an eccentric cam is fit runs through the base of the piston. One end of the rod projects out to the edge of the sub-base and is bent to form a large handle. As the handle is turned by the parent, the eccentric cam rotates and forces the piston up past the top surface of the pedestal disk to press against the underside of the seat base, effectively jamming the two assemblies together.

Attachment to Wheelchair
Metal blocks with a vertical hole 3/4" in diameter are clamped to the front edge of the arm rests on each side of the wheelchair, extending forward. A pair of 3/4" steel tubes is mounted to the underside of the seating device's sub-base. The whole seat assembly can then be dropped into the holes in the blocks. The height of the infant seat on the wheelchair can be adjusted by repositioning stops on each tube.

EVALUATION AND MODIFICATIONS

The completed prototype seat was delivered to the mother and used quite successfully for several months until the child outgrew it. As the child grew in size, a larger seat was built. This second prototype incorporates a number of improvements. It has longer feet and head sections which can be easily replaced with ones of different sizes. The seat is made out of vinyl and covered with washable cloth liners velcroed into place. The underside and back of the vinyl covering are laced together to allow for adjustments in the contours of the seat. A lightweight, removable tray is provided as a play surface for the child.

DISCUSSION

This seat, together with support services and numerous smaller adaptations provided by TLG staff, dramatically impacted the mother's ability to independently attend to the physical and emotional needs of her infant throughout the day while her husband was at work. It has significant potential to be of value to other quadriplegic parents, whether mounted on a wheelchair or table. Different models and sizes might be made available on an exchange basis as the child grows, or retrofit kits could be offered.

Additional features envisioned for the future models include:

- A retracting sun screen to protect the baby when out-of-doors.
- A cross bar from which to hang toys for the child's entertainment
- Small rings on the side of the seat enclosure from which to tether toys and other items which the child might throw or knock off the seat.
- Side pockets on the seat enclosure for small items which the parent might want access to.

Although the size and maneuverability of the seat allowed the parent to negotiate doorways, approach appliances, and perform similar activities, having it attached to the wheelchair all the time was restricting. A means to attach and remove the seat from the wheelchair with limited hand involvement is being designed as a follow-up project to this one.

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A POWERED MOBILITY AID FOR PRE-SCHOOL CHILDREN WITH CEREBRAL PALSY

Dr Roger Orpwood
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Abstract

The early development of children with cerebral palsy can be impaired by a lack of mobility in their pre-school years. This paper describes the design and development of a powered mobility aid specifically tailored to the needs of very young CP's. A team approach was used involving the engineer, the therapist and many end users to evolve a suitable design and to take into account the particular abilities and postural control requirements of children with CP. Two final devices were developed, a pre-school and a slightly larger version. About 25 of these have been in use for periods up to two years and have demonstrated the effectiveness of providing independant mobility for such young children.

Background

There are many children with Cerebral Palsy (CP) who are unable to walk during their pre-school years. It is well documented that immobility during a child's formative years can impare their cognitive development because they are unable to explore their environment and develop a spacial perspective. Consequently it is important for such children to have access to an aid which can provide them with independent mobility from age around 18 months and throughout their early formative years.

Statement of the problem

There is therefore a need for a powered mobility aid for very young children with CP. Such a device needs to fully take into account the particular postural problems of such children and if possible provide some physical therapy as well. It also needs to address the control difficulties that such children experience. In order for the device to be accepted by the children and by their parents it needs in addition to have the appearance of a toy rather than a powered wheelchair. And finally the device must take into account the growth of the child and the fact that one device may be used by several children in an institutional setting.

Rational

We have developed a design methodology for devices for people with disabilities that recognises the crucial importance of the user interface in the success of the device. The methodology uses a team approach to design involving the engineer, the therapist and the end user. It initially conentrates on exploring design solutions for the user interface though an iterative process with much testing and evaluating of potential prototypes en route. Early work on the mobility device used rough wooden mock-ups to check whether certain design approaches were appropriate and effective. Only when the design team were happy that all user aspects had been investigated and successful solutions to the user interface found that much effort was expended in providing the more "engineering" aspects of the design such as motor/gearhead, power supply and control, etc.

Design

The design that resulted used a postural support system that sat the child astride a seat to encourage as much leg abduction as possible. Adjustable support surfaces were provided to stabilise the child through foot plates, thoracic plates and a hand support bar. The centre of gravity was kept as low as possible for stability with the wheel centres higher than lowest foot position. Power was provided through two 12V wormgear-headed motors supplied by a sealed 25Ah rechargeable battery. Speed was adjusted to give a maximum of about 1.5 mph. The child's control was provided through a joystick mounted on the hand support bar that controlled the motors through a purpose designed electronic controller. The controller provided a soft start and stop, and included logic to allow steering in the forward direction but not in reverse (this was found to be necessary from early work with children). The body shape was designed to give the device the appearance of a toy (see illustration).

Development

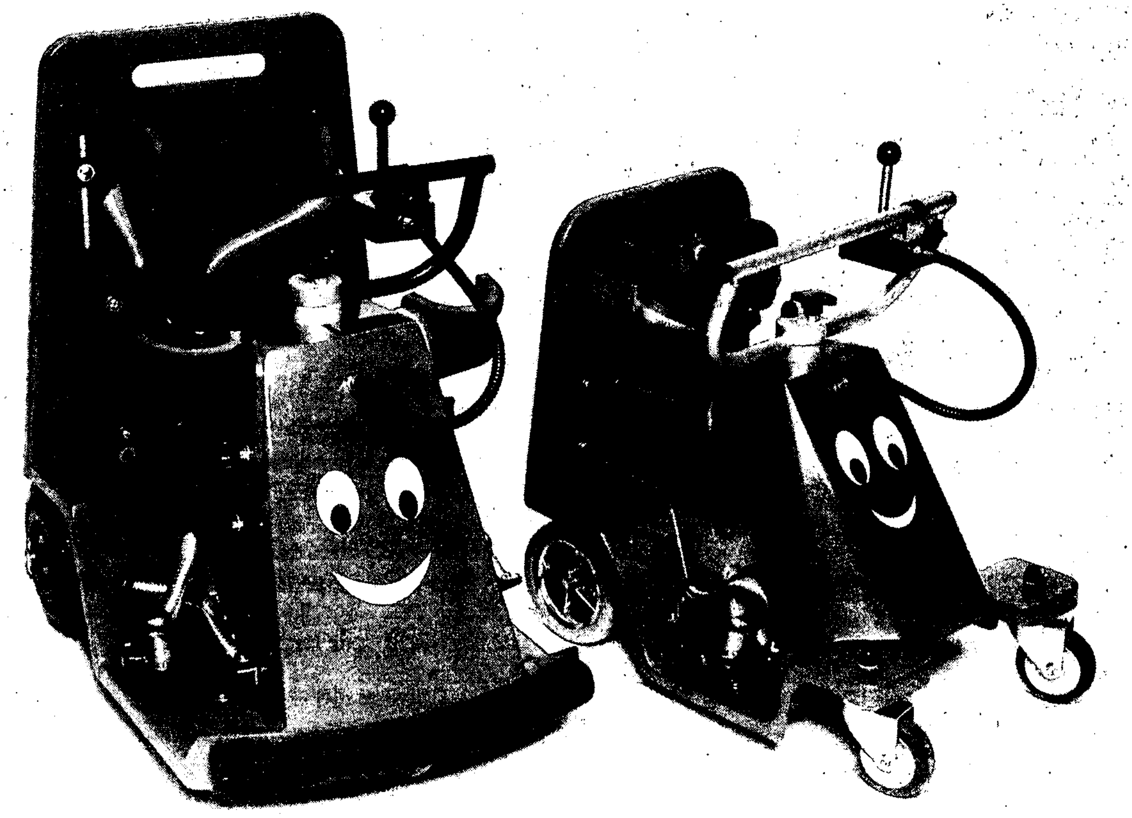
It was found after several children had used the device that there was a need for a slightly larger version. The larger device uses three wheels to allow more room for forward adjustment of the footrest. Users also wanted a higher speed option so the drive system was developed to provide a high and low maximum speed, with a top speed for the larger device of around 3 mph which was acceptable for people walking alongside the device when going to the shops etc.

Evaluation

Extensive evaluations took place during the evolution of the design but to fully test the device about 25 have been made available for use by local children over a period of two years. In order to manufacture these cheaply and to improve the appearance of the devices the bodies were moulded in fibreglass. The whole structure was simplified in this way as the body now consists simply of two fibreglass mouldings; one comprising the upper body and child support surfaces, and the other the power module with the motors, battery,etc.

Discussion

The results have been extremely encouraging. The increase in mobility has had a profound affect on development and on motivation. The device has enabled a couple of children to stay in a main stream infant school. Rather than being stigmatised through using the device, the children find that their peers are quite envious and want to ride on it with them. Simply the look on their faces communicates very well the fun the children have with the device. The joystick control provides good physical therapy in that it encourages good arm control, and the children have to learn to control extensor spams of the arm to enable them to steer the device in the forward direction. It is felt that the device could help a large number of children with CP and discussions are underway to see if it could be made available commercially.



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MOBILITY AND MOBILITY TRAINING FOR SEVERELY DISABLED CHILDREN: RESULTS OF THE "SMART" WHEELCHAIR PROJECT

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ABSTRACT

Powered mobility aids can provide important learning experiences as well as independence for severely disabled, non-mobile children. However, conventional powered chairs do not meet the needs of all children. A three year evaluation of 12 "smart" wheelchairs for mobility and mobility training of this group is described, results reported, and conclusions discussed.

BACKGROUND

Independent mobility is crucial for development of physical, cognitive, communicative and social skills. Recent studies [1,2] have shown that use of powered mobility aids can provide developmental benefits for severely disabled, non-mobile children. The majority of these studies have used conventional, joystick controlled wheelchairs. The aim of the Smart Wheelchair [3] programme is to develop augmentative mobility aids to provide independent mobility for children who cannot access conventional chairs, and investigate how they affect development. Part of the study focused on use of the chairs for mobility and mobility training, and the results are the subject of this paper.

RESEARCH QUESTION(S)

The mobility study asked three key questions:

• Can profoundly handicapped children gain functional mobility by using a wheelchair where control is augmented by a computer or other external agency (*augmentative mobility*)?

• What are the characteristics of an augmentative mobility aid which support the development of the skills needed to control a normal powered wheelchair?

• To what extent do existing powered wheelchairs (as supplied by UK statutory services and privately funded) meet these criteria?

METHOD

Thirteen children in three special schools evaluated ten Smart Wheelchairs for between 4 and 20 months during the evaluation period. The children were aged between 3.5 and 15.5 and a heterogeneous group was deliberately chosen in collaboration with school staff and parents to test the full breadth of system application. Chairs were used by different groups of professionals for different purposes, at home and in residential care environments.

The aim of the broader programme was to investigate the effects of augmentative mobility upon all aspects of children's development - physical, cognitive, social, perceptual - as well as mobility. The investigation therefore asks not only how the system can be used to train for and provide mobility, but to measure the usefulness of that mobility for each individual child. The wide brief required a wide range of measurement tools [4]:

• Pre- and post-intervention profiles generated through structured interviews with staff and parents, covering all aspects of development;
• Video recordings and computer-based transcription and analysis;
• Standardised driving tests;
• Chair Database, recording faults and technical modifications to each chair;
• Regular meetings with staff and parents in each school.

RESULTS

Changes in mobility skills were measured using product measures such as profile charts. Process measures - diaries, videos, databases and video transcription and analysis were used to investigate factors influencing these changes. The results of analysis of each case study took several forms:

• Graphical Continuity Charts, showing time on task for each session; staff/parents involved; controls and chair tools used; and progress milestones;
• Case Studies, summarising profiles and intervention;

- Statistics and plots from computer-based analysis of transcribed videos.

All of the children learned new driving skills and two (who had previously been assessed and rejected for powered wheelchairs) progressed to complete control over conventional joystick-controlled chairs. Children demonstrated other improvements in areas such as: posture; physical manipulation; assertiveness; curiosity; communication [5].

DISCUSSION

Although the power of single case design is by definition based upon analysis of each individual child, a common pattern of progress is evident. Most children began with a switch or control which they had previously used with other assistive technology (although some were provided with new controls) and minimal chair tools. Once some experience of movement had been gained, more complex chair tools were introduced to provide experience of more varied mobility. As the child's control and understanding of mobility, so responsibility for control passed from chair to child and the use of chair tools decreases. The training scheme therefore attempts to provide the child with a motivating, safe environment for learning mobility skills in a principled and systematic manner.

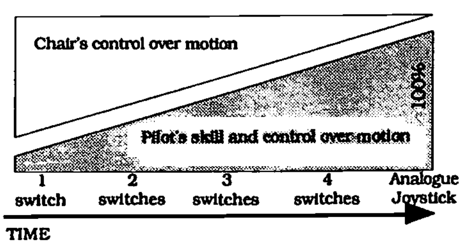

Figure 1 : Skill progression

Within this common skill progression children made widely varying progress: while two achieved complete control over their chair using proportional joysticks without any Smart tools, others reached a plateau some way short of this. In particular, the quick progress of three children [6] using a "mobility training chair" suggests that slightly more able children can make significant gains with quite minimal practice. Examination and comparison of the case study material suggests several factors influencing individual progress:

- Personal factors such as age and baseline;
- Number and length of chair sessions.
- Activities during chair sessions.
- Staff and parent expectations, attitude and ethos
- Perceptions of the child

SUMMARY

1. Independent mobility through powered wheelchairs enhances all areas of life and development of disabled non-mobile children. The Smart Wheelchair has proven to be an effective means of assessing, training and maximising powered mobility skills as well as offering experience of mobility.

2. The progressive training scheme developed allows specific skills to be learnt at a pace appropriate to the child's abilities.

3. The period of training can vary widely: one child progressed from a single switch to joystick control over a conventional powered chair in 4 months, while another took 14 months.

4. Successful use of a Smart Wheelchair relies upon continual accurate assessment and observation, sufficient opportunity for practice and suitable learning activities. Training of staff in its use is therefore essential.

5. The most important features of a basic Smart Wheelchair [7], in order of priority, are: switch control; motion tools; collision sensors (Bump Tools); 'Observer' speech synthesiser. Although only one child used the 'Listener' facility of driving the chair from a laptop computer, this may reflect the mix of particular cases and developmental stage of the children more than the usefulness of the tool. The Listener allows augmentative communication aids such as Light Talkers to drive the chair via the RS232 port. Systems based on laptop computers, such as the *Voice Navigator* voice recognition software, or the *E Z Keys* writing/communication/environmental control system can also connect and drive the wheelchair. The practical use of these possibilities requires evaluation.

6. The basic chair provides a range of control options and strategies for dealing with collisions which have been shown to be effective for mobility training and to a lesser extent, for providing functional mobility. Achieving full independent mobility still demands a relatively high level of control from the user. The limited evaluation of the Line Follower and Rangefinder tools to date suggests that less able children might achieve a higher level of independence using these tools compared with the collision sensing tools. These extended tools should be evaluated in greater depth.

7. While some features of the Smart Wheelchair design are available on other systems, we know of no other design providing the breadth of facilities in one modular package. The philosophy of designing a symbiotic system to complement changing individual needs is also novel. Similarly, while assessment and training for mobility skills is practised informally and effectively using conventional and adapted powered wheelchairs, the Smart Wheelchair project is unusual in attempting to investigate and develop effective design and intervention techniques and support materials.

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WHEELCHAIR BATTERY OVERDISCHARGE & OVERCHARGE PROBLEMS

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ABSTRACT

A wheelchair battery usually doesn't become overdischarged since protective circuits in the wheelchair controller prevent this action. However, if the battery is left discharged after use it will spontaneously continue to discharge, especially at high temperature. In a week or so the battery may become so overdischarged that it will not take a charge. This problem, called excess sulfation of the cells, requires special procedures to overcome. Methods for partially correcting overdischarge sulfation are discussed and the results of an experimental program are presented.

In order to fully charge a lead-acid **wet cell** the charger must put more energy back into the battery than needed, the overcharge amount, to ensure that the acid is properly mixed and cells are uniformly charged. During the overcharge phase the charger voltage exceeds the gassing voltage and the water in the battery is separated into hydrogen and oxygen gas which leaves the battery. Wet cell batteries then require periodic distilled water addition. Experimental and theoretical calculations are given for this effect, and a rewater time is calculated.

INTRODUCTION

The lead-acid battery used in electric wheelchairs, etc., operates by an electrochemical reaction between a negative plate of porous spongy lead, a positive plate of porous lead dioxide, and a dilute solution of sulfuric acid called the electrolyte. Each pair of plates, called a cell, produces an open circuit voltage of 2.1-2.5 volts. The amount of electrical energy available in each cell depends on the quantity of active spongy lead, lead dioxide, and electrolyte. Six cells connected in series in a polypropylene case make up a "12 volt" battery, and two of these batteries connected in series are typically used to operate a "24 volt" motor driven wheelchair.

The charge/discharge reaction of a lead-acid battery, called the double sulfate reaction, is well known [Ref. 1], and is shown in Equation 1. During discharge of the battery (right to left, Eq. 1) lead dioxide is reduced to lead sulfate at the negative plate, and spongy lead is oxidized to lead sulfate, so that both plates become partially covered with lead sulfate crystals. When the battery is charged the reaction in Eq. 1 is reversed and the lead sulfate is converted back to spongy lead and lead dioxide at the appropriate plate. This process is more complicated than shown, but is essentially correct.

$$2PbSO_4 + 2H_2O \rightleftharpoons PbO_2 + Pb + 2H^+ + 2HSO_4^- \quad (1)$$

A lead-acid battery can become overdischarged by leaving the battery in a discharged state for a few weeks due to the self discharge characteristics of the battery. When this happens, the battery will not accept a charge with a standard charger. The normal electrochemical action during discharge of converting the plates to lead sulfate as shown in Eq. 1 will produce an excess coating of lead sulfate crystals as well as enlarged crystals if overdischarged that prevents the battery from accepting the charge. We have been investigating this failure mechanism and in the next section will present some of our test results.

OVERDISCHARGE SULFATION

Lead-acid batteries that are left in a discharged state for a few weeks or have too high a concentration of electrolyte or are operated at too high a temperature (above 43 °C) become excessively sulfated with enlarged crystals and refuses to accept a charge. This problem is described in several battery books, e.g. [2] and [3]. During routine testing of tubular positive plate lead-acid batteries for wheelchairs, the discharge circuit control was accidentally bumped causing the battery to be discharged to zero volts at the terminals. When these batteries were placed on charge they would not accept a recharge. The original capacity of these batteries is shown in Fig. 1 in terms of current during discharge versus the time of discharge. For example, at 5 amps discharge current, a typical average wheelchair use, the original condition of the batteries would allow a 16 hour discharge if discharged to 1 volt/cell.

The battery manufacturer recommended that these overdischarged batteries be placed on a long (40 hour) charge at a low current of 3.5 amps. Using a constant current power supply gave test results shown in Fig. 1 under "1st Restored," where after this treatment the batteries had recovered most of the lost capacity; at 5 amps discharge current the batteries would now operate for only 12 hours, 75% of rated capacity.

A typical 10 amp taper charger starts charging around 9-10 amps and slowly tapers down to a finish rate of about 1.5 amps. A constant current charger was available which charges at 4.3 amps until almost fully charged and does a finish charge at 2.5 amps. During charging the taper charger reaches the gassing voltage of 2.4 V/cell much sooner than the constant current charger. It was decided to switch to a constant current charger to see if the over sulfated batteries could be improved. This method of charging did not show any improvement over the original slow charge recommended by the manufacturer.

Finally, the method recommended in the battery books, e.g. [2] and [3], of replacing the electrolyte with pure water when in the discharged state was tried. Note that discharging the battery depletes the acid in the electrolyte since the acid has combined with lead to coat the plates with lead sulfate. The batteries are then recharged using the low constant current charger and the charged electrolyte tested to see that it has the proper specific gravity of about 1.26 but not over 1.28. The results of this test are shown in Fig. 1 as "2nd Restored," where it is seen that the battery has not improved over the "1st Restored" capacity. However, the battery now has all cells uniformly charged, which did not occur prior to this test, and this would give better performance during end of capacity discharge.

Overcharge Water Loss

When a wet cell battery is charged it is normal to overcharge 10-20% in order to stir up the acid in the cells and equalize the charge of the cells. This overcharge has the effect of gassing the water in the battery and requiring that the battery be replenished with distilled water every few months. If the liquid level is not maintained above the plates permanent damage will result and the capacity of the battery declines. Maintenance free batteries of the gelled or starved electrolyte type should not be overcharged, and chargers that are designed for these batteries should be used.

Overcharging electrolysis of the water in the battery is called a secondary reaction [1] of the battery, and is shown by Eqs 2 and 3.

$$H_2O(liq) \rightarrow 1/2\ O_2(gas) + 2H^+ + 2e^- \qquad (2)$$

$$2H^+ + 2e^- \rightarrow H_2(gas) \qquad (3)$$

These equations state that for every 2 moles of overcharge electrons passing through the battery 1 mole of water is converted to hydrogen and oxygen which escapes from the battery. Using this information it is possible to develop an equation that relates the ampere-hours of overcharge to the loss in water volume of the battery. The first step is to convert X amp-hrs overcharge to water loss in grams, as shown in Eq. 4.

$$X amp\text{-}hrs \frac{3600 s}{hr} \frac{mole^-}{9.65E4 amp\text{-}s} \frac{mole H_2O}{2 moles^-}$$

$$x \frac{18 g}{mole H_2O} = 0.3358 X\ g H_2O \qquad (4)$$

Next convert grams of water to volume of water.

$$.3358 X g H_2O \frac{1 cc}{g} \frac{1 inch^3}{16.39 cc} = .0205 X inch^3 \qquad (5)$$

Using the result from Eq. 5 a comparison between the theory and experimental data for the tubular positive lead-acid battery under test is shown in Fig. 2. The theory and test results are in very good agreement.

DISCUSSION

All of our results for overdischarge of the battery show that it is possible to partially correct for the problem of overdischarge sulfation, but this correction is not simple. People using a typical taper charger will not be able to repair their batteries because the current is too high. Thus, it is very important to prevent the batteries from becoming overdischarged. One rule of thumb to help to prevent overdischarge sulfation is to **recharge your batteries every night** following any use of the wheelchair as long as you have a charger that automatically cuts off when the batteries are charged so they do not become severely overcharged. This rule would apply to wet cell, gelled cell, and starved electrolyte cell, maintenance free or not, but only if you have an automatic cut off charger designed for the batteries you are using.

In the case of overcharge of wet cell batteries, and these are the most economical batteries to use [4], it is important to replenish the water in the batteries using distilled water when it gets low as checked under a fully charged condition. If you add water when the batteries are discharged the water may exceed the available space for water since the volume of the water increases when charged. Our tests, Fig. 2, will give the required frequency of water addition. For a typical wheelchair battery, size 22NF of 50 amp-hr capacity, the charger would overcharge about 15% of capacity, or 7.5 amp-hrs per charge. For a 22NF wet cell the water volume above the plates is about 7 cu.-in., which corresponds to 300 amp-hrs in Fig. 2. Assuming the battery is charged every night, the number of nights before the water above the plates is depleted would be 300/7.5 = 40 nights, at which time water must be added to avoid damage to the battery.

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Fig. 1 Battery Capacity
Discharged to 1 V/cell @ 27 oC

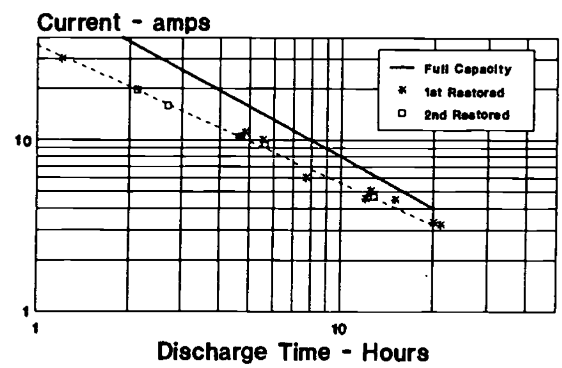
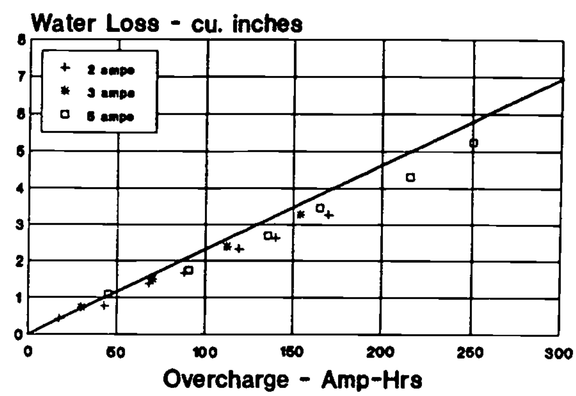


Fig. 2 Overcharge Water Loss



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NEW TECHNOLOGY FOR WHEELCHAIR BATTERIES

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ABSTRACT

Battery technologies presently being developed for electric vehicles (EVs) are reviewed with regard to their potential for application in electrically powered wheelchairs. Specific attention is given to the battery development efforts of the United States Advanced Battery Consortium (USABC), an alliance formed between government and industry to develop batteries for electric automobiles. Considerations of cost, reliability, safety, availability, and maintainability are discussed.

BACKGROUND

Virtually every commercial electric vehicle, including the wheelchair, uses a lead-acid battery. Lead-acid has been the most reliable, cost effective, and practical battery on the market for decades, mainly because the automotive industry has spent millions to improve both the battery and the mass production process. These efforts have been key to the development of the electric wheelchair. However, the relatively small size of the market for wheelchair batteries provides little incentive to optimize the lead-acid battery or to develop improved technologies specifically for wheelchair use. Wheelchairs must therefore continue to incorporate technologies developed for larger markets with better economics of scale.

Fortunately, electric automobiles are practically being mandated now by several state and local governments. The result is renewed industry-wide interest and infusion of funds into the development of batteries with performance capabilities which, consequently, are very well aligned with the needs of the wheelchair user. USABC's charter is to develop an economical electric automobile for public use by the year 2000. The first commercial batteries are expected to begin production sometime in the mid-1990s. Their performance targets represent a 4-fold improvement over lead-acid in almost every respect. Funding for USABC and independent efforts are expected to approach $1 billion over the next 10 years. So the focus, the funding, and the economics of scale are all falling into place.

DESIGN

Size, weight, cost, reliability, life, safety, availability, and maintainability are some of the primary design issues facing the battery developer. Size and weight are a direct function of the performance capabilities of the battery versus the required drain rates and durations. Cost depends upon purchase price, cycle life, and maintenance costs. Price is typically determined by the inherent cost of raw materials and the number of units sold.

Reliability and life, or the battery's ability to perform without failure for some number of cycles, are interdependent. They are affected by system complexity; chemical and electrochemical stability of the battery materials and components; frequency and degree of excursions beyond the designed maintenance and/or usage profiles; and the number of reliability growth cycles (build/test/correct) conducted to identify and drive out defects.

Examples of potential safety issues include violent or unexpected releases of stored pressure energy or electrochemical energy, or the ignition of battery materials or evolved gasses. Safe operation must be ensured even under severe conditions of abuse such as puncture or temperature extremes.

Availability and maintainability are somewhat related. Availability refers to the time a battery is available for use versus the time it spends undergoing recharge, scheduled maintenance, repair or reconditioning. Maintainability, refers to the frequency, complexity, and cost of keeping the battery in operating order. User involvement in maintenance should be minimized.

STATEMENT OF THE PROBLEM

For the wheelchair application, size and weight are accommodated in order to exploit the reliability, safety, availability, maintainability, and cost benefits of the lead-acid battery relative to other existing technologies. There still remains a need however for improved reliability through cycle life, and reductions in size and weight. In a survey conducted by Brubaker et.al. (1), over 70% of the users had encountered battery problems which required repair in the previous 12 months. Bode (2) reported that the basic size and configuration of the lead-acid battery limits frame design, space for respirators, etc. Reductions in battery weight or volume might also be used to improve portability. A more portable electric wheelchair could provide significant cost advantages, particularly if specially equipped transport vans and handling equipment

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could be eliminated. Improvements in size or weight must not be obtained at the expense of reliability or safety however.

DEVELOPMENT

The development goals for electric vehicle batteries seem to be well aligned with the improvements needed for wheelchair batteries. Table 1 shows the USABC mid-term (1995) and long-term (2000) goals compared against present levels of lead-acid performance. As can be seen, if even the USABC mid-term goals are achieved, considerable improvements in wheelchair performance could be expected.

Table 1. Relevant USABC battery goals vs average Pb-acid wheelchair battery performance.

Performance Characteristic	Mid-term	Long-term	Pb-acid avg
Energy Density (Wh/l)	135	300	70
Specific Energy (Wh/kg)	80	200	35
Power density (W/l)	250	600	>200
Specific Power (W/kg)	150	400	>100
Life (Years)	5	10	1-2
Cycle Life (to 80 % DoD)	600	1000	>300*
Price ($/kWh)	<150	<100	<150
Min. Operating Temp.(°C)	-30	-40	-40
Max. Operating Temp.(°C)	+65	+85	+60
Recharge Time (Hr)	<6	3-6	6-8
Maintenance	none	none	none
(* to 60% DoD)			

The most likely candidate technologies for EV use are shown in Table 2. The systems are classified by electrolyte type and operating temperature. All aqueous systems operate at ambient temperature.

Table 2. Candidate technologies for EVs.

AQUEOUS		NON-AQUEOUS	
Acid	Alkaline	Ambient Temp.	High Temp.
Pb-acid	Fe/Ni Cd/Ni MH/Ni Zn/Ni Zn/Br Zn/Air	Li/Polymer	Li/FeS_2 Na/S $Na/NiCl_2$

Of the technologies listed in Table 2, USABC has chosen to fund the four shown in Table 3 (3). The remaining technologies are being funded independently by government and/or private organizations.

Table 3. Technologies funded by USABC to date.

Technology	Company	Funding ($M)	Timing
MH/Ni	Ovonic	19.9	Mid-term
MH/Ni	Saft	18.1	Mid-term
Na/S	Silent Power	12.1	Mid-term
Li/FeS_2	Saft	17.3	Long-term
Li/Polymer	W.R. Grace	27.4	Long-term
Li/Polymer	Delco-Remy	28.0	Long-term

EVALUATION

Each of the candidate technologies has a unique set of advantages and disadvantages summarized briefly here.

Pb-acid: (Lead-acid) Advanced Pb-acid development work is focused primarily on improving cycle life and specific energy. A case receiving considerable attention is the Horizon battery being developed by Electrosource, Inc. and BDM, Inc. Developers claim that the battery is capable of quick charging in less than 3 hours and delivering 20% more energy than state-of-the-art lead acid (4).

Fe/Ni: (Nickel-Iron) This battery is already in use in several Chrysler electric vans. However, the battery is being used primarily to demonstrate other system components (motors, controllers, etc). Its main disadvantage is poor charging efficiency which results in frequent water additions as well as the evolution of hydrogen gas. These safety and maintenance issues keep it from being seriously considered for further development.

Cd/Ni: (Nickel-Cadmium) This battery is also presently available and being used in test vans. It also suffers from water make-up requirements, although to a much lesser extent than Fe/Ni. Its energy density is almost double that of Pb-acid, but it is relatively expensive as are all the nickel-based couples. Environmental issues and the emergence of the MH/Ni battery will probably preclude any serious efforts to develop it for EVs.

MH/Ni: (Nickel-Metal Hydride) This battery is a relative newcomer but is making dramatic progress as one of the USABC funded technologies. It has been pursued as an environmentally safe replacement for small cylindrical Cd/Ni cells. Now, full-size 1.2 kWh modules have been built and 25 Ah cells have achieved over 400 cycles with energy densities 2-3 times the Pb-acid (5). Issues include: thermal management, which should be less critical for the smaller wheelchair battery; elevated internal cell pressures, a safety issue which is addressed through vent and case design; capacity loss on stand, a materials issue; and materials cost, which will appear to require recycling to bring costs into line with the $150/kWh targets. This maintenance free battery would appear to be an encouraging near-term candidate for wheelchair demonstration.

Zn/Ni: (Nickel-Zinc) This battery has potentially the highest energy density and lowest cost of any of the Ni-based couples. Cycle life, reliability and cost are the major issues. Attempts to develop full-size EV cells have failed in the past due to the poor cycle life of the zinc anode, which dissolves in alkaline electrolyte causing dendritic shorting, electrode shape change, and loss of capacity.

Zn/Br: (Zinc-Bromine) This battery was conceived originally for stationary applications such as power plant load levelling. Demonstrations in electric vehicles have been conducted however. Zinc solubility has detrimental effects on this battery also, and periodic regeneration of the battery is required. The system is a flow-cell arrangement. Reservoirs, piping, and pumps for electrolyte circulation add complexity to the system making reliability and safety a concern, especially considering the toxic nature of bromine gas. The flowing electrolyte system may make it difficult to scale this battery down to sizes appropriate for wheelchair use.

Zn/Air: (Zinc-air) This battery is being actively tested in vans by DEMI, Inc in the USA, and by Electric Fuel, Ltd in Europe. Specific energies 4-5 times that of Pb-acid are reported (6). And the zinc-air battery probably has the potential for the lowest manufactured cost of any of the systems. However, zinc solubility in alkaline electrolyte creates maintenance, reliability, and cycle life problems with Zn/Air much as with the other alkaline Zn couples. Other issues include: poor volumetric energy density; reliability concerns surrounding a complex set of auxiliaries needed to pump electrolyte and/or scrub carbon-dioxide from the air. Difficulties can be anticipated in trying to scale this system down for wheelchair use.

Li/FeS$_2$: (Lithium-Iron Disulfide) As one of the USABC funded technologies, this battery promises energy and power densities 6-7 times that of Pb-acid. Because it operates at over 400 °C, it is completely sealed in a thermal enclosure and is therefore maintenance-free. Presently, the key issues include: cycle life related to ruggedness of separator systems; safety related to the amount and form of reactive lithium contained; and cost related to the manufacture of cell components. Because it may be most efficient to package an entire EV battery in a single thermal housing, batteries developed for EVs may not easily scale-down to modular form for wheelchair use. Westinghouse has however demonstrated a smaller 1.2 kWh, 60 Wh/kg version of the Li/FeS$_2$ battery which should fit into the wheelchair. Production is scheduled for 1995.

Na/S, Na/NiCl$_2$: (Sodium-Sulfur, Sodium-Nickel Chloride) These are sister technologies. Both have been demonstrated to provide 4-5 times the power and energy density of lead-acid. Reliability and ruggedness of the solid beta-alumina electrolyte are issues. Safety can be an issue particularly as cell sizes are scaled up. The Na/S system also faces a special safety problem associated with the possibility of generating poisonous hydrogen sulfide gas. Both systems operate above 300 °C and therefore require thermal enclosures which, as mentioned for Li/FeS$_2$, may present scale-down problems.

Li/Polymer: (Lithium-Polymer) This battery promises inherently low material costs and specific energies or energy densities 6-8 times Pb-acid. Primary issues are safety (related to the reactivity of lithium) and power (related to poor conductivity of the organic electrolyte). Safety issues are being addressed via development of an intercalated lithium anode with reduced reactivity, while power issues are being addressed through improvements in electrolyte formulations. Sealed, maintenance-free cells have already been produced in small sizes. If successful, this battery could replace all others, and it should scale easily to wheelchair use.

SUMMARY AND CONCLUSIONS

An improved wheelchair battery will be a spin-off of batteries developed for larger markets. The emerging electric vehicle market is fueling battery development efforts which will directly benefit the wheelchair community. Two technologies being developed, nickel metal hydride and lithium-iron disulfide, may be available as early as 1995 for wheelchair trials. If successful, these technologies could provide 50 to 60% weight and volume savings over existing lead-acid batteries. Reliability, cycle life, and safety are yet to be determined.

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AN AUTOMATICALLY-GUIDED POWERED WHEELCHAIR FOR THE SEVERELY DISABLED

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Abstract

This paper describes the development of an automatically-guided powered wheelchair for use by the severely disabled. The navigation of the wheelchair system is based on the accurate determination of the wheelchair's position and orientation within its environment. This is accomplished by combining samples of the wheelchair's drive wheel rotations along with observations of passive visual cues which are placed at discrete locations within the environment. The passive visual cues are observed by two small video cameras mounted on the wheelchair. The wheelchair tracks from one station to another in a home or office environment by following pre-taught reference paths. The user of such a system need only input the desired destination within the home or office setting. The entire system has been successfully developed and has been tested within laboratory, office, and apartment settings.

Background

For some disabled individuals, the use of a joystick or other standard user-interface device may become difficult, tedious, or even impossible while controlling a wheelchair through the precise trajectories necessary to navigate within a home or office environment. These same individuals may, however, be able to choose a desired destination from a menu-driven input device. If the powered wheelchair could automatically and safely navigate to the chosen destination, the independence and mobility of the individual would be greatly enhanced.

Many navigation methods for mobile robots have been developed for use in industrial settings. However, little research has been focused on the use of autonomous vehicles in the tight confines of home or office environments. Some methods have been investigated concerning the assistive navigation of powered wheelchairs. An autonomous wheelchair that follows guide tracks which are embedded in the floor has been recently developed [1]. This type of navigation, however, is inflexible to changes in the environment and could be impractical to implement and maintain due to the variety of complex paths which are required for household or office navigation. Another system has been developed as an assistive navigation method for powered wheelchairs [2, 3]. This system interprets the joystick inputs from the wheelchair user and then modifies the navigation of the wheelchair to avoid any obstacles that are in the path of the wheelchair. Thus, control of the wheelchair is shared between the user and the automatic guidance system. However, this system does not possess an adequate means for assessing the global position and orientation of the wheelchair within its environment.

The navigation and control of the wheelchair system described in this paper is based on the ability of the system to determine accurate estimates of the position and orientation of the wheelchair within its environment. Paths which take the wheelchair from one station to another are taught to the system during a one-time teaching session. After the user selects a desired destination, automatic guidance of the wheelchair is accomplished by tracking the set of taught reference paths which takes the user from his or her current position to the desired destination. A complete description of the theory underlying the wheelchair's estimation and navigation methods is given in [4] and [5].

Method

The experimental wheelchair system is pictured in Figure 1. This wheelchair is driven by two rear wheels which are actuated independently for steering control. For this drive configuration, shown schematically in Figure 2, a novel set of differential equations have been derived [5]. These equations relate the differential wheel movement of the two drive wheels to the differential position and orientation of the wheelchair. In Figure 2, the position of a point on the wheelchair is denoted by X and Y, while the orientation of the wheelchair is denoted by ϕ. The differential equations can be integrated numerically by measuring the wheel motion of the two drive wheels via devices known as optical shaft encoders. Estimates of the wheelchair's position and orientation produced by this numerical integration have been referred to in the literature as "dead-reckoning." However, if there are any initial estimation errors, modelling errors, or disturbances (such as wheel slippage), then errors in the wheelchair's position and orientation estimates produced by dead-reckoning will grow as the wheelchair travels throughout its environment. Therefore, some type of observation about or measurement of the surrounding environment must be made to correct any errors in the dead-reckoned estimates of the wheelchair.

Figure 1: Wheelchair system.

Two video cameras are placed below the seat of the wheelchair to observe visual cues which are placed at discrete positions within the wheelchair's environment. Using a pin-hole camera model, the horizontal position of a cue in the image plane of a camera mounted on the vehicle is related algebraically to the position and orientation of the wheelchair within its environment. The ring-shaped, elliptical patterns, shown with the wheelchair in Figure 1, are used as the visual cues for the wheelchair system. These patterns are rapidly and robustly detectable from a discretized image. Through an algorithm known as the extended Kalman filter [6], the observations of the visual cues are used to update and correct the estimates of the wheelchair's position and orientation based on dead-reckoning alone. For the wheelchair system, the extended Kalman filter produces position estimates which are globally accurate, typically, to within an inch and orientation estimates which are accurate, typically, to within one degree.

Based on the accurate position and orientation estimates produced by the extended Kalman filter, desired reference paths are *taught* to the vehicle. The wheelchair system is taught by manually guiding the wheelchair through the desired path. During the teaching procedure, estimates of the wheelchair's position and orientation are generated. The taught path is then saved in a manner which is compatible with a tracking procedure which in turn is used to repeat the taught path. Many paths which would take the user from one station in the home or office to another station would be taught and recorded during a one-time teaching session. Teaching allows the automatic wheelchair system to operate without the use of precise maps of the environment and also minimizes the effect of any physical errors in the measured locations of the visual cues.

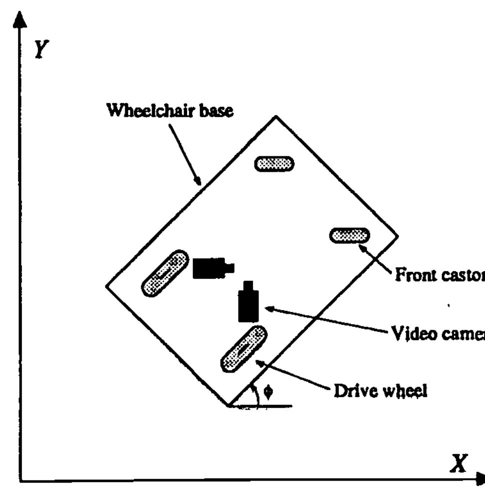

Figure 2: Wheelchair schematic.

During the tracking of the desired taught paths, errors in the current estimated position and orientation of the vehicle relative to the taught path are computed. The taught path is then tracked using a PID control algorithm to reduce the estimated error between the vehicle and the path. A novel formulation of the control algorithm allows the velocity of the wheelchair to be adjusted independent of the tracking of the path. Thus, the velocity of the wheelchair can be adjusted based on separate considerations such as the safety and the accuracy of the system.

Results

The wheelchair system described above has been successfully developed and has been tested in a laboratory, an office, and an apartment setting. Video documentation of the wheelchair system while navigating throughout the tight confines of an office setting is available [7]. In this video, the system navigates from room to room (through doorways), and approaches various destinations within the rooms including desks, bookshelves, etc. The wheelchair system has been tested with and without passengers (0 – 200 lbs).

An Everest & Jennings Tempest model powered wheelchair is outfitted with a 80386-based personal computer, two CCD video cameras, and two devices known as optical shaft encoders which are used to measure the drive wheel rotations. Control of the drive wheel motors is accomplished by interfacing the personal computer directly with the wheelchair's joystick control box.

Discussion and Conclusions

The basis for the successful development of the wheelchair system described in this paper lies with the ability of the system to accurately determine the wheelchair's position and orientation within its environment. The control of the wheelchair can then be accomplished on three different levels: traditional joystick control, shared control, or pure autonomous control once a destination has been chosen. Accurate estimates of the wheelchair's position and orientation will always be available no matter how the system is being controlled. This capability allows for a greater degree of flexibility in the navigation and control of the wheelchair.

In the current stage of development of the wheelchair, no obstacle avoidance procedures have been implemented. If the user shares control of the wheelchair with the automatic guidance system, the user can help to override the guidance system and navigate the wheelchair around the obstacle as suggested in [2, 3]. In the future, the system will incorporate a proximity sensor on the wheelchair either to alert the user that the chair is in danger of colliding with an obstacle, or to navigate the chair around the obstacle automatically. Note, however, that if the taught reference paths remain obstacle-free, the wheelchair will never be in danger of colliding with any obstacles.

The automatically-guided wheelchair system described in this paper results in a unique aid which would provide a measure of autonomy for the severely disabled. The system gives the disabled the capability, which might be otherwise unavailable, to navigate precisely throughout their home or office environment. Thus, the daily tasks which are routinely performed in a home or office could be accomplished without the aid of a caretaker, thereby allowing the user of such a system to be more independent and self-sufficient.

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Intelligent Omnidirectional Wheelchair with a Flexible Configurable Functionality

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ABSTRACT

This paper presents an omnidirectional wheelchair provided with an open control architecture allowing a flexible configuration of user required functionality, which is essential for an individual adaptation to the special needs of severely physically disabled and mentally handicapped people. The demand for a large functionality with high flexibility, leads to a modular structured control system, composed of different smart units. Each unit is provided with local intelligence to yield a high independence from other modules as well as to get an open control system.

BACKGROUND

The use of power wheelchairs is one of the great steps towards the integration of severely physically disabled and mentally handicapped people, enableing them self-controlled mobility without external help. However, many of them, especially those with restricted psycho-mental capabilities, are not able to operate conventional wheelchairs. There are two reasons why those systems can not address these people: their limited mobility and the restricted functionality. Normal domestic environments (e.g. bathrooms) are often complex structured and therefore require a high manoeuvrability. Because of their kinematic constraints, conventional wheelchairs are hardly suitable to move within packed rooms. An increase of the mobility could be reached by the use of omnidirectional driving concepts, which give an all-around freedom of motion.

In order to offer the people with restricted capabilities a higher degree of independence, the wheelchair has to be provided with an expanded functionality allowing to control it on different levels of abstraction. That means, besides the 'normal' user-controlled movement by simply using a joystick, several additional modes of operation, which can be represented as layers within a hierarchy of functionality (see fig. 1), should supply the user. For example, using basic sensor systems a collision avoidance would support the user to generate safe movements. Proceeding within the hierarchy an environment guided movement can be helpful when driving along a corridor or through a door. Special complex manoeuvres like play-back (re-driving a recorded path, e.g. in the bathroom) or back-tracing (inversion of the recent manoeuvres) ease the control of the wheelchair in specific situations up to a task-oriented control, which represent the top of the hierarchy.

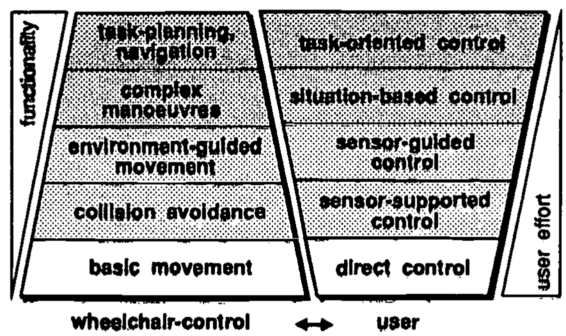

Figure 1: Hierarchy of wheelchair functionality

The figure 1 reflects the distribution of effort between the user and the control system. As the wheelchair becomes more autonomous by using the higher-level control, the burden on the user becomes less. While the functionality increases, safety aspects become more important. In order to get an individually adaptable aid to the handicapped, the wheelchair functionality should be easily adaptable to the specific handicaps of the user. Consequently, the system has to be flexible configurable allowing transitions between the different layers.

METHOD

Omnidirectional Drive Concept

To satisfy the demand of a higher mobility, new driving concepts have to be taken in consideration. Wheeled mobile robots (WMR) with omnidirectional steering capability are wellknown in the field of robotics, e.g. Muir [1] has proved that WMRs using four omnidirectional, actuated and sensed wheels provide three degree-of-freedom (DOF) locomotion, so that any combination of forward, sideways, and rotational movement is possible.

System Architecture

The demand for a large functionality with high flexibility, leads to a modular structured control system, composed of different smart units. Each unit is provided with local intelligence to yield a high independence from other modules as well as to get an open control system. This enables a flexible reaction and increases the reliability because of a mutual verification of the transferred data. Figure 2 shows the system architecture as well as the hardware design.

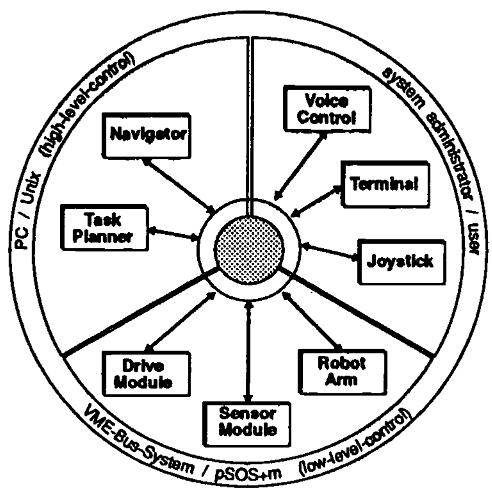

Figure 2: System Architecture

The different modules share an identical underlying structure, which is illustrated in fig. 3. The main components of the module structure are the local knowledge base, the inference mechanism, the communication unit and the functional unit (see fig. 3).

The communication unit is responsible for the module interaction, which is based on a mesage-passing-mechanism. To establish a fault tolerant module interprocessing, the modules exchange their interface specificaton, i.e. they enter the identification number of modules, which are compatible to them in a so-called communication link list. This enables the different modules to reorganize their communication if an error occurs. For example, within an initial state the terminal informs the other modules that it is able to process user input/output data. In case of a terminal error, those modules, which try to communicate with the user via this device, look within their communication link list whether there is another module accepting input/output data in order to reorganize the interaction with the user.

The module knowledge is represented in a hybrid knowledge base [3]. On the one hand the declarative knowledge, including facts about the module status, the functionality and the links to other modules, is stored in the data base. On the other hand the rule base contains the procedural knowledge about how to act in dependence on the available data (e.g. it holds the information how to react in case of an error or absence of a module).

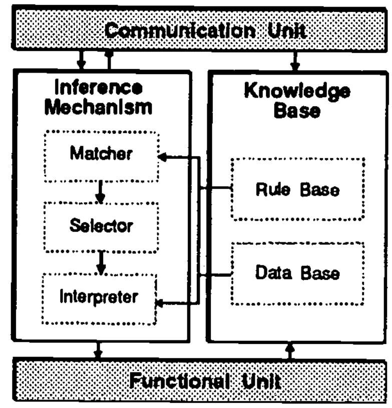

Figure 3: Module Structure

The processing of the declarative and procedural knowledge by the inference mechanism runs through three phases: First, the matcher identifies all applicable rules, i.e. those whose conditions match the facts stored in the data base. From amongst the set of applicable rules, the selector determines within the second phase that rule, which should be executed by evaluating the priorities attached to them. Finally, the interpreter executes the conclusion of the selected rule. The effectuation of the rule conclusion can delete, modify or create new facts in the data base or cause elementary actions.

The functional unit consists of a set of functions, which operate the specific module hardware/software resources. For example, the functional unit of the drive module includes algorithms to control the wheelchair position. The functions are activated by the interpreter and may change the module status.

Based on the proposed system architecture consisting of the different smart modules, the required reliability and flexibility can be yield, so that the wheelchair functionality can be individually adapted to the specific handicaps of the user.

RESULTS

As a result, a prototype wheelchair (see fig. 4) equiped with four so-called Mecanum wheels has been developed, able to move with three DOF in a plane, so that in spite of its floor constraints, the wheelchair almost has the movability of a hovercraft. The protoype wheelchair has demonstrated the increase of mobility that can be yield by the use of such omnidirectional driving concepts, which allow to move even within packed indoor environments because of a non-restricted positioning capability. The omnidirectional wheelchair not only overcomes the kinematic constraints of conventional ones and provides the user with a higher manoeuvrability, but also allows to simulate other wheelchairs with steering axes, which makes it useful for an individual training.

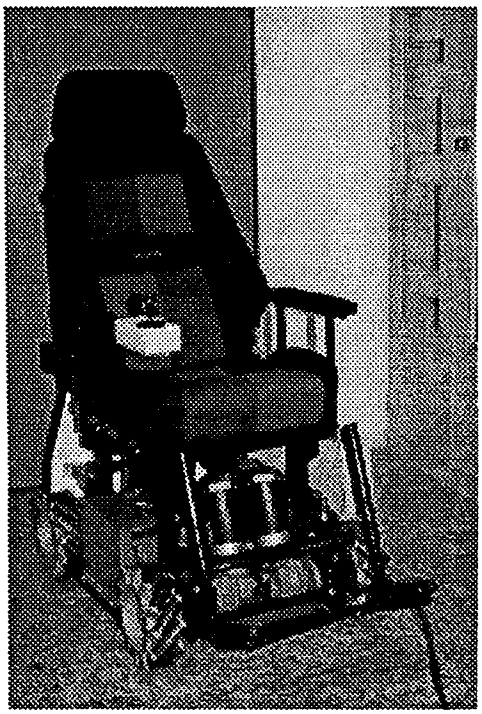

Figure 4: Wheelchair Prototype

The functionality allows a sensor-supported and sensor-guided control of the wheelchair using ultrasonic and infrared-sensors to avoid collisions or to support the user e.g. by driving through a door.

DISCUSSION

In this paper, an omnidirectional wheelchair is presented, which is provided with an open control architecture, allowing a flexible configuration of an individually adaptable functionality. The system architecture consists of different intelligent modules, which are able to organize their interaction by themselves. Because of the self-organizing feature of the module communication mechanism and the modular architecture, the system is open and its functionality can easily be expanded, so that the integration of high-level processing, such as task-oriented programming, path-planning etc., requires no system modification. The distributed intelligence allows the design of a fault tolerant system that means, using the local knowledge base the system is provided with the capability to continue the operation with reduced functionality in case of the absence of a module from the system. The presented control architecture makes it feasible to act on different levels of abstraction and supports the user with several modes of operation, e.g. movement with sensoric, back-tracing, playback, etc. Because of the modular structure, special features of the omnidirectional driving concept, e.g. the simulation of other wheelchairs with steering axes, can easily be realized for an individual training.

Furthermore, the open architecture of the control system is able to integrate technically modified and/or additional devices, e.g. a robotic service arm or special user interfaces. This allows to compensate specific handicaps and gives an adjusted and matched system to the individual.

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INITIAL EVALUATION OF POWER ADD-ON UNITS FOR LIGHTWEIGHT WHEELCHAIRS

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ABSTRACT

A power add-on unit (PAU) is a motor system that can be attached to a lightweight manual wheelchair, on a part-time basis, to give it powered chair capabilities. To lay the groundwork for developing new designs, research was done on consumer needs and on the state of the art in PAU technology. Three commercial and two experimental PAUs were tested and evaluated by seventeen panelists, including eight consumers (wheelchair riders), five designer/builders, two dealers, and two physical therapists who prescribe wheelchairs. Conclusions from the study include:

1) confirmation of the need for new PAUs,
2) identification of two primary target user populations for which to design new products,
3) detailed comparative evaluations of tested units,
4) comprehensive design criteria for development of new PAUs.

BACKGROUND

A PAU-equipped manual wheelchair can offer full- or part-time powered propulsion plus the range of private and public transportation options available to manual chair riders, including automobile and air travel. It can also provide a rider with both a powered and manual wheelchair within strict funding limits, or facilitate the transition from manual to powered riding or vice versa.

PAU development work has been ongoing since 1984 at the Center, including the design and prototyping of the "Click 'N' Zoom" PAU. Three hypotheses provided the impetus and basis for this project: 1) target user populations that could benefit from and would buy new PAUs can be identified, 2) available PAUs are not adequately meeting the needs of these populations, and 3) a consumer-driven approach to design--involving consumers in design, testing and evaluation--is essential to success in developing assistive technology.

METHOD

The research included survey questions and the testing and evaluation of five PAUs. We used a detailed questionnaire to collect design recommendations, information about users' abilities and needs, and results from the evaluations of test PAUs.

Members of the consumer panel were chosen to represent a range of the disability and mobility device types that would likely be interested in PAUs. The five test units were selected to represent the broadest possible range of PAU design features.

RESULTS

<u>Comparative Evaluations of Tested PAUs</u>
Panelists ranked the following eight subject areas in order of importance:

1) Operation Under Power
2) Safety
3) Performance
4) Attachment and Removal
5) Durability and Reliability
6) Value
7) Stowability
8) Aesthetics

1) In Operation Under Power, the tiller-steered Roll-Aid unit was rated highest overall, by a good margin. It excels on sideslopes and curb cuts and in moderate-speed turns. Its braking is too abrupt, however. Damaco was rated next-best, followed closely by Sweeney and Click 'N' Zoom. Damaco is superior for driving in reverse and is generally capable, but its controller produces an annoying, jerky ride at high speeds. Its traction drive works poorly when wet, as does Sweeney's. Sweeney was rated best at high speed turns and braking, because of the responsiveness provided by its direct hand/arm-actuated control, and is good at maintaining direction. However, it lacks powered reverse. Click 'N' Zoom runs well on wet ground, but has one major problem: in turns or hard maneuvers the drive wheels scuff against the ground causing loss of traction, vibration, floor abuse, and noise. Samson was rated extremely low overall for powered operation. Turning control is difficult even for strong riders, plus braking is unassisted by the unit and requires the rider to first shut the power off. The unit lacks powered reverse, and manual reverse is inconvenient.

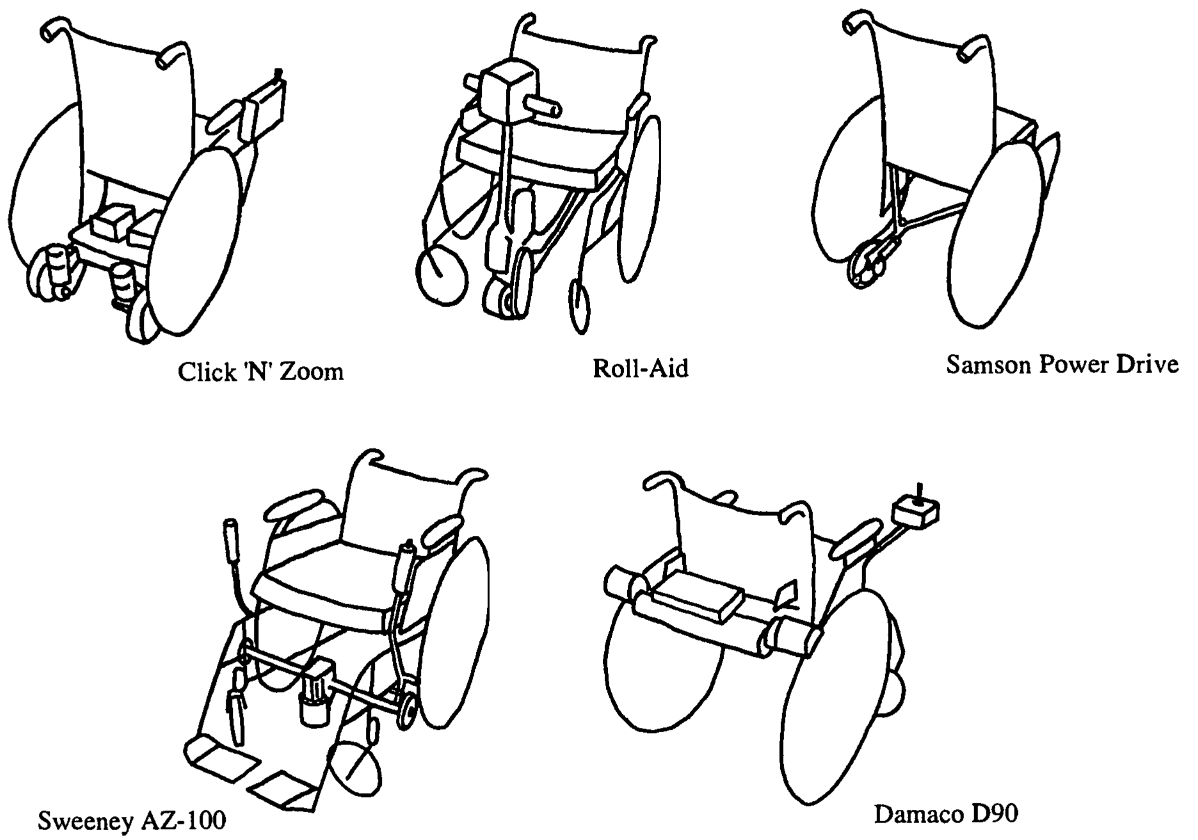

Figure 1. Power add-on units that were tested and evaluated.

2) Safety ratings favored Sweeney by a small margin, and gave Samson very low marks. Sweeney was favored for its braking and the ease of switching to manual operation in case of power failure. Samson is also easy to switch to manual mode, but unsafe due to control problems. Neither Roll-Aid nor Click 'N' Zoom can be switched to manual operation except by removing the unit from the wheelchair. Roll-Aid can handle sideslopes most safely, but its three-wheeled stance creates tipping instability, especially on uneven terrain, and its braking is too abrupt. Damaco and Click 'N' Zoom both tend to lose traction with the ground in difficult driving situations.

3) Performance ratings reflect speed on flat ground and inclines. Flat ground speeds ranged from three to four miles per hour. Damaco and Roll-Aid shared the high marks, Click 'N' Zoom the middle, Samson and Sweeney the bottom.

4) For Attachment and Removal characteristics, Samson was strongly preferred over the other units, because it has the fewest, lightest, and smallest parts, although it requires torso mobility and hand strength and dexterity. Damaco was rated lowest because of tricky connections, and the difficulty of accessing parts behind and underneath the seat. Sweeney and Click 'N' Zoom are the least demanding of manual dexterity. Roll-Aid allows a strong rider to independently attach the unit, once assembled, but has many parts, one of which is heavy at 35 pounds.

5) Durability and Reliability ratings had little spread. Click 'N' Zoom, Damaco and Sweeney will require frequent drive wheel and/or tire replacement.

6) Value ratings indicated which of the five units panelists would choose if all were the same quality of manufacture. Damaco was highest-rated, with Sweeney close behind. Samson's rating was distinctly low, because of operation and safety concerns.

7) For Stowability, the number and weight of parts were the most significant factors. Samson was the strong leader, followed by Sweeney. Roll-Aid and Click 'N' Zoom were weakest.

8) Aesthetics ratings favored the least visible and audible units, Samson and Sweeney. The unfinished-looking, noisy Click 'N' Zoom scored lowest.

CONCLUSIONS AND RECOMMENDATIONS

The Need for New Power Add-On Units
Input from the professional and consumer panelists, plus our in-depth evaluation of some representative commercial PAUs, led us to conclude that a significant need for new PAU designs does exist. The study confirmed our original hypothesis that some specific user populations could be better served by PAUs than by conventional powered wheelchairs or scooters, and we have identified many ways in which currently available PAUs do not adequately serve the needs of these populations. Further market research is needed, however, to estimate the sizes of user populations.

Target User Populations
We have defined two target population groups for which manufacturers of new PAUs ought to design. The needs of the two groups are probably too different to allow any single design to accommodate both of them well. The two groups together include a broad range of all potential PAU users.

Group A consists of manual wheelchair riders who can propel themselves on hard, level surfaces but could benefit from powered assistance on difficult terrain, long distances, or tiring days. They need a PAU that can be easily attached and removed by the rider while seated in the wheelchair.

Group B members are full- or nearly full-time riders of powered wheelchairs or scooters who need 1) access to private and public transportation options that cannot easily accommodate a standard powered chair; and/or 2) the option of manual propulsion, by rider or attendant, in some situations; and/or 3) a minimum-cost powered mobility option.

We recommend that two different designs of PAU be produced to serve each of the target user populations groups A and B.

Design Criteria for New PAUs
A comprehensive set of design criteria was prepared to assist designers and manufacturers of PAUs. The criteria are marked to indicate which ones are important to meet the specific needs of Group A and B riders. While we recommend that designers and manufacturers focus upon user groups A and B, our comprehensive design criteria could also be useful to designers who investigate and define different target user population(s) and then modify the criteria to fit.

For Group A riders a new design should incorporate many of the assets of the prototype Sweeney PAU by featuring a single motor, no electronics, simplicity and ruggedness, no part heavier than 20 pounds, and easy switching between manual and powered operation. It should allow attachment and removal by the seated rider, accommodate cambered wheels and/or a rear axle position that is optimized for manual propulsion, and retail for under $1,000 with batteries. It is acceptable to require bilateral hand and arm use, and some arm strength, but it should not require good torso stability.

To meet the needs of the largest number of Group B riders, a PAU should be designed both for group members who are the least physically able (by accommodating attendants and unfamiliar helpers), and for those who will sometimes propel the chair manually (by making it easy for the seated rider to switch between manual and powered propulsion). For Group B the best solution is likely a PAU and wheelchair matched set, designed for dual use. It should feature joystick control, an attachment system that is obvious and foolproof enough for an untrained assistant to use, operation characteristics and reliability comparable to low-cost conventional powered chairs, automatic hands-off braking, and a retail price below $2,800 with batteries or $3,700 (the Medicare cap) with batteries and wheelchair.

PAUs for both groups must provide safe operation, including tipping stability and rider-initiated free-wheeling that doesn't require removing the PAU. Unit and batteries must be easy to stow and transport via private and public vehicles, including cars and airplanes. Designs using traction against wheelchair tires should either be avoided or designed for insensitivity to wet riding conditions.

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Electromagnetic Compatibility (EMC) Of Powered Wheelchairs and Scooters

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ABSTRACT

Based on recent reports of powered wheelchairs exhibiting unintended movement, laboratory tests were performed at the Center for Devices and Radiological Health (CDRH) to examine the susceptibility of these devices to interference from radio and microwave transmissions. The testing confirmed that these devices are susceptible to electromagnetic interference (EMI). CDRH has developed an EMC testing protocol for powered wheelchairs and scooter over the frequency range of 26 MHz to 1 GHz. The protocol was presented to the RESNA standards committee for possible inclusion into the voluntary RESNA Electric Wheelchair Standard, Part 14. This paper will describe some of the EMI concerns for medical devices as well as test methods and results. The need to improve EMI immunity is an important issue for medical devices.

BACKGROUND

As technology advances in the medical device arena, more and more devices incorporate complex electronics and microprocessors. While there are many advantages to such designs, these types of electronics can be sensitive to interference from electromagnetic (EM) radiation, electrostatic discharge (ESD), and other sources. Electromagnetic Compatibility (EMC) is the broad term used to describe how devices react to the EM environment. Because of the complexities of the devices and the EM environment where the devices are used, susceptibility to interference cannot be predicted reliably. Direct testing of the devices in a controlled EM environment is necessary. With appropriate design and testing, medical devices such as wheelchairs can be made to function properly within realistic EM environments.

Within the last 2 years there have been several incidents related to uncontrolled or unwanted movement of powered wheelchairs, or scooters, which strongly suggest EMI to the control systems. Obvious concerns for user safety prompted CDRH to investigate the EMC of these devices.

RESEARCH QUESTIONS

The initial problem was to discover to what degree powered wheelchairs and scooters were susceptible to radiated EM. Once this was demonstrated, the focus shifted to finding the sources of susceptibility and examining approaches to address the problem.

METHODS

EMC testing of the chairs was performed in a Gigahertz Transverse Electromagnetic cell (GTEM), and in an anechoic chamber. The chairs were exposed to various electric field intensities over the frequency range of 1 MHz to 1 GHz. This range is where most of the common EM transmissions (radio, TV, microwave, cellular telephones, CB, mobile radios, etc.) occur. The exposures were varied in field strength between about 3 V/m and about 40 V/m. The GTEM exposure fields were created with a digitally controlled signal generator and radio/microwave frequency power amplifier. The exposure fields strengths were controlled and recorded via forward and reflected power meter readings fed to a PC computer. Using this system, and Quick BASIC computer language programs, a power leveling procedure was developed which controlled the volumetric exposure field uniformity (without the chair in the field) to about $\pm$ 6 dB. Similar techniques were used to control the anechoic chamber fields.

The wheelchairs were placed into the GTEM in predetermined exposure fields and subjected to known field strengths over the 1 MHz to 1000 MHz range. Reactions of the chairs, such as brake release and wheel movement were monitored during the testing. Two main tests where developed for the exposure situation: chair stationary but power on, chair active with the wheels moving at 25% to 50% of their maximum.

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RESULTS

Each powered wheelchair and scooter that was tested exhibited some degree of susceptibility to the exposure fields. Many of the newer microprocessor controlled chairs were susceptible to fields strengths as low as 5 V/m. This corresponds to the fields strength produced by a 4 watt hand-held radio transmitter at a distance of about 7 feet. Each chair has its own characteristic susceptibility as a function of frequency and field strength. Figure 1 illustrates a typical powered wheelchair reaction to the exposure field, shown as the wheel speed versus frequency. For this test the joystick was fixed in place to hold the wheel speed to about 30 RPM. Large deviations around the 30 RPM base speed can be seen at several different frequencies (e.g. 120, 150, 220 MHz)

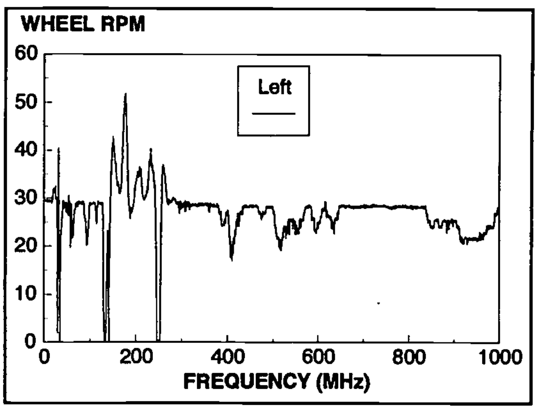

Figure 1. Sample powered wheelchair EMC test at 20 V/m, wheel speed changes versus exposure frequency.

The test results and experience gained from the testing, along with consultations with the manufacturers, led to the development of proposals for the RESNA Standards Committee. In these proposals there are specific test protocols for the powered wheelchairs and scooters. For example, the testing must be performed at a minimum frequency step rate of 1 MHz with a dwell at each frequency for at least 2 seconds. This is needed because these devices may react very slowly to the exposure field, and shorter dwell times or larger frequency steps could miss chair reactions.

DISCUSSION

Radiated EMC testing has large inherent uncertainties. There are also uncertainties in how the device might be exposed in its user environment. The number of sources of EM energy (radio, TV, cellular telephone, mobile and hand radios, other medical device, etc.) are increasing rapidly, as are the number of medical devices employing electronics. However, our previous work with apnea monitors, and the present work with powered wheelchairs, has clearly demonstrated that good basic design and shielding techniques can eliminate most of the EMI problems.

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SIG-10
Electrical Stimulation

TRANSCUTANEOUS ELECTRODE IMPEDANCE MEASUREMENT SYSTEM

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ABSTRACT

A transcutaneous electrode impedance measurement system has recently been developed to measure the distribution of impedance over the surface of commercially produced electrical stimulation electrodes. This system uses an IBM PC/AT computer to acquire data from up to 640 test points located against the electrode under test. A commercially available stimulator is used to drive the electrode and impedance at each of the test points is determined during the middle 60% of the first phase of a symmetrical biphasic stimulation pulse. This system will be used to characterize the current distribution performance of skin electrodes used for therapeutic and functional applications of electrical stimulation.

BACKGROUND

Electrical stimulation has been firmly established as a significant treatment modality. Common applications include transcutaneous electrical nerve stimulation (TENS), therapeutic stimulation for the treatment of stroke and spinal cord related disabilities, functional electrical stimulation to restore motion or other lost or impaired function due to stroke, spinal or other forms of neural injury, as well as many other applications too numerous to mention. The most common method of delivering the energy of electrical stimulation in these applications is through the use of transcutaneous skin electrodes.

In most applications of electrical stimulation is it desirable to evenly distribute the delivery of electrical energy over the active surface of the transcutaneous electrode. It is important to have a relatively low overall impedance so that the stimulation equipment is only burdened with the tissue impedance for the delivery of sufficient current to elicit the desired stimulation result. Commercially available electrodes have many challenges to deliver low impedance, dynamic geometric conformatity to the body contours during stimulation, even dispersion of current density, good adhesive properties, little or no allergic reactivity, long life and low cost. Often some balance must be reached to achieve what is perceived to be the most important of these features. The large number of manufacturers of electrodes with varied materials and design features make it difficult to sort out the best performers of devices available.

OBJECTIVE

Most of the features of a skin electrode may be readily observed clinically but the evaluation of electrode impedance/current density distribution is the most elusive. Previous researchers [1,2] have described measurement techniques and electrodes designed to evenly distribute impedance, but there exists no exhaustive method to readily characterize the current passing capability of an electrode.

Our objective was to develop a system to easily determine the distributed impedance of a skin electrode during symmetrical biphasic square waveform electrical stimulation in a repeatable and, preferably, automated manner. The system described below is the result of our efforts.

METHODS

The Electrode Test System (ETS) consists of an IBM 486 computer with a data acquisition system, a commercially available electrical stimulator, a test fixture for either two inch by five inch (or smaller) electrodes or ten inch by ten inch (or smaller) electrodes and a switching system which allows the computer data acquisition system to sample each of the test points in turn.

The commercially available stimulator used in the present system is the MicroStim Portable Neuromuscular Stimulator (Medel, Hamburg, Germany). This stimulator can produce symmetrical biphasic stimulation pulses and may be triggered by an external source. The data acquisition system is able to trigger the MicroStim and samples the resulting waveforms at 250 KHz. Data from the middle 60% of the first phase of the biphasic waveform are used in the calculations.

IMPEDANCE MEASUREMENT SYSTEM

The two inch by five inch test fixture consists of 16 rows of 40 gold plated test pads arranged on 1/8 inch centers. The pads are circular and have an area of 2 mm^2. This represents a total of 640 separate test points for a two by five inch electrode. Smaller electrodes may be tested, however fewer of the test pads will be in contact with the electrode.

The ten by ten inch test fixture consists of 25 rows of 25 gold plated test pads arranged on 1 cm centers. The pads are square and have an area of 1 cm^2. This represents a total of 625 separate test points for a ten by ten inch electrode. Again, smaller electrodes may be tested with fewer of the test pads in contact with the electrode.

Each pad of the test fixture is loaded to the indifferent stimulator leadwire through a series 1000 Ohm 1% tolerance resistor. When a test point is to be evaluated three measurements are made. First the total stimulator current is measured, then the voltage applied across the electrode under test is measured, then the current through the 1000 Ohm resistor is measured. With these three measurements the calculation of the impedance at the test point is straight forward. The switching of the test points to the data acquisition system is mediated by the switching assembly and controlled by the computer and data acquisition system.

Upon completion of data collection the impedance information may be summarized for each run or averages of several runs may be tabulated. The results of impedance analyses can be directed to a laser printer and output and command files are generated for Excel (MicroSoft Corporation, Redmond, Washington) and three graphics presentation software systems: Perspective Junior 3D (Three D Graphics, Pacific Palisades, California) , Tecplot (Amtec Engineering Inc., Bellevue, Washington), and Axum (TriMetrix Inc., Seattle, Washington).

RESULTS and DISCUSSION

Preliminary trials have consisted of evaluations of PALS [1] electrodes manufactured by Axelgaard Manufacturing Company (Fallbrook, California). The ETS has thus far performed well to determine the distributed impedance of this series of electrodes. It is intended that the system will be used in the near future to compare the performance of a number of electrodes from different manufacturers. The system will also be used to compare the impedance distribution changes by modifications to the chemical makeup of the conducting gel formulations and the current distribution media used in the manufacture of skin electrodes. It is predicted that this system will allow fast, accurate and impartial evaluation of electrode technologies so that clinicians and patients alike can benefit from an increased knowledge of electrode performance.

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AN INSTRUMENTED GRASP SENSOR FOR QUANTITATIVE EVALUATIONS OF NEUROPROSTHETIC HAND GRASP SYSTEMS

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ABSTRACT

A lightweight, hand held, instrumented hand grasp sensor has been developed to monitor grasp opening and force produced by quadriplegic subjects using a neuroprosthetic hand grasp system. The device allowed the quantification of grasp control properties to be performed quickly in an outpatient clinic, and provided data on both lateral and palmar grasps.

BACKGROUND

Functional neuromuscular stimulation has been utilized as a method of restoring limited hand function in C5/C6 level quadriplegia, [2, 3]. The portable hand neuroprosthesis developed at Case Western Reserve University allows the subject to control grasp and release of the paralyzed hand. The neuroprosthesis user is provided with two selectable grasp patterns: lateral prehension, generally used for grasping small objects; and palmar prehension, typically used to grasp larger objects [2]. The subject uses a position transducer mounted at the shoulder to modulate a command signal that is sent to an external microprocessor-based stimulator, which then sends a stimulation pattern to the muscles of the forearm and hand through a multi-channel implantable stimulator. In order to optimize the synthesis of the hand grasp patterns, it is necessary to provide a method of quantitatively evaluating the outputs of the system, i.e., the force and position of the hand. A variety of instruments have been used to compare grip strength or pinch strength in unimpaired individuals to that of disabled or injured persons. The devices utilize different transduction techniques: measuring air pressure developed from squeezing a balloon; utilizing springs or cables connected to calibrated displays; or measuring hydraulic pressure. Several of the more recently developed instruments utilize strain gauges because of their accuracy and repeatability, and the ability to interface the instruments with a computer. In therapeutic hand evaluation, grip force and the position of the hand are typically not measured simultaneously. Forces are measured at preset positions or position is not monitored. A measurement of both grasp opening and force is required to fully characterize the function of a neuroprosthetic hand grasp.

An initial study to quantitatively evaluate a neuroprosthetic hand grasp involved the simultaneous recording of grasp position and force to create a visual feedback signal utilized in visual pursuit tracking tasks [1]. Grasp force was measured by a pair of parallel plates attached to a table-mounted force sensor. Grasp opening was detected by a joystick angle transducer which was connected to the back of a finger brace. While the tests were able to be performed satisfactorily, mounting and calibration of the joint angle transducer was time intensive and created some limitation on joint movement. In addition, the table-mounted force sensor made evaluations at different wrist positions more difficult. While force and position sensors mounted on the fingers and thumb were an alternate method of making these measurements, the mounting and calibration procedures required for adequate accuracy were too time-intensive for the quick evaluations which were needed. The desire to quantitatively evaluate neuroprosthetic hand grasp systems as part of a subject's routine clinical visit necessitated the development of a grasp force and position sensor which could be set up quickly and easily in an outpatient clinic.

DESIGN

The specifications for the force transducer were that it should be able to measure forces up to 50 N, which is larger than the grasp forces produced by neuroprosthesis users [1]. The desired resolution for the force sensor was 0.1 N. The force measurement should be independent of the placement of the hand on the device. The specifications for the position detector were that it should allow measurement of a range of grasp openings from 1 cm (about the diameter of a pen) to about 7 cm (the diameter of a beverage can). The desired resolution for the position sensor was 1 mm. Additional requirements of the sensor were that it had to be able to measure grasp force and position in both palmar and lateral grasps. Since some neuroprosthesis users utilize a wrist position transducer to control their neuroprosthesis, the grasp force and position sensor had to be mobile (ideally hand held) to allow for wrist movement. This requirement indicated that the sensor must be lightweight and fit comfortably in the hand. To allow the evaluations to be performed quickly, the device needed to be able to be mounted easily and be able to be calibrated prior to the subject's arrival.

The hand grasp force and position sensor consisted of two rectangular plates made of lightweight plastic, connected by three sets of hinges (Fig. 1). The plates were large enough to allow four fingers to fit comfortably and had the following dimensions: 11 cm long, 4 cm wide and 0.3 cm thick. The function of the hinge sets was to limit motion of the plates to one axis, so that a force applied to the plates resulted in the plates moving towards or away from each other while remaining parallel. At the same time, only a small amount of force was required to squeeze the plates together. Low-stiffness torsion springs between the hinge extensions forced the plates to separate as the hand opened, so that the distance between the plates correlated to grasp opening. This configuration allowed a maximum opening of 8.2 cm and a minimum opening of 1.1 cm (when the plates touched). The force applied to the plates was measured by a miniature load cell (Sensotec model 13) which was embedded in the center of the bottom plate. The load cell was 9.5 mm in diameter and 3.0 mm high and had a load capacity of 111 N (25 lbs). The calibration factor for the force output was 9.90 Newton/volt. The distance between the plates was monitored by an optical linear position encoder. The resolution of the position encoder was 0.31 mm. The calibration factor for the position output was -1.64 cm/volt.

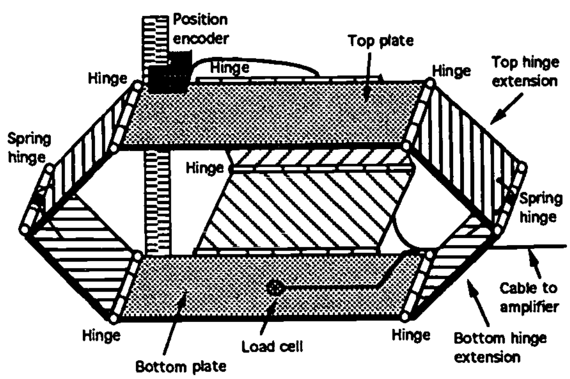

Fig. 1. Instrumented Grasp Sensor

Different-sized lightweight spacers were placed between the plates (Fig. 2), allowing force measurements at different fixed positions, simulating different-sized objects being grasped. The spacers were attached to the upper plate by a magnet in the top of the spacer, which was coupled to a magnet which was embedded in the upper plate. This allowed the spacers to be switched quickly during an experiment. Compliant spacers, such as springs, could also be placed between the plates to simulate compliant objects. The grasp sensor was lightweight enough to be held by quadriplegic subjects with weak grasps. The sensor, without spacers, weighed 67 grams, and the spacers weighed 5 - 8 grams. Velcro or double-sided tape could be used on the plates to assist the subject in holding the device.

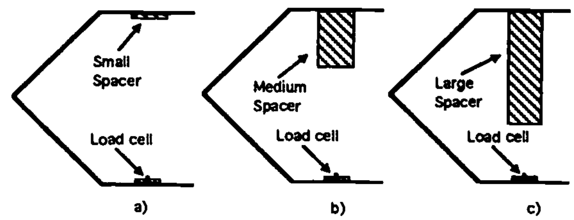

Fig. 2. Cross-section of sensor with different spacers

EVALUATION

Methods The grasp sensor was utilized in visual pursuit tracking tasks to quantify the input/output properties of the neuroprosthesis and to study subjects' abilities to control their system. The input/output properties were evaluated by monitoring the system output (grasp opening and force) as the system input (command) was varied from 0 to 100%. Trials were performed with different sized spacers in the grasp sensor and at different wrist positions. For the tests on control abilities, subjects were presented with a target track (either a ramp, step, or randomly varying track) on a monitor. The subjects used a feedback track (a combination of grasp opening and force), which also was displayed on the monitor, to follow the target track. Tracking error was defined as the normalized root mean square error between the feedback and target tracks.

Results Tests were performed on six quadriplegic subjects with hand grasp neuroprostheses as part of their regular outpatient clinic visit. Examples of the input/output properties for a subject using the palmar grasp are shown in Figs. 3 and 4. Force versus command and grasp opening versus command are shown for trials at different wrist positions (Fig. 3) and for trials with different sized spacers (Fig. 4). In all the trials, grasp opening began to decrease as the command reached 40% and continued to decrease until contact between the spacer and the bottom plate occurred, after which the force began to increase. In Figure 3, with the wrist extended, the fingers are passively flexed, resulting in a smaller initial grasp opening. Thus, contact occurred sooner (at 45% command), and force began to increase sooner. Greater forces are also obtained with the wrist in an extended position. In Figure 4, contact happened later (at 75% command) with the small spacer, causing the force to increase later. Greater forces were applied with the medium spacer than with the small spacer. For this subject, the initial 40% of the command range is used to orient the thumb for palmar grasp, which does not cause a change in the grasp opening.

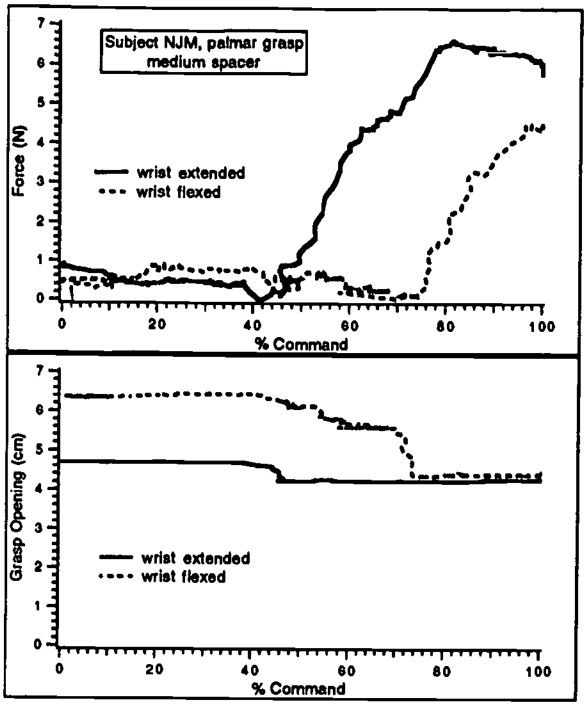

Fig. 3. Input/output data for different wrist positions

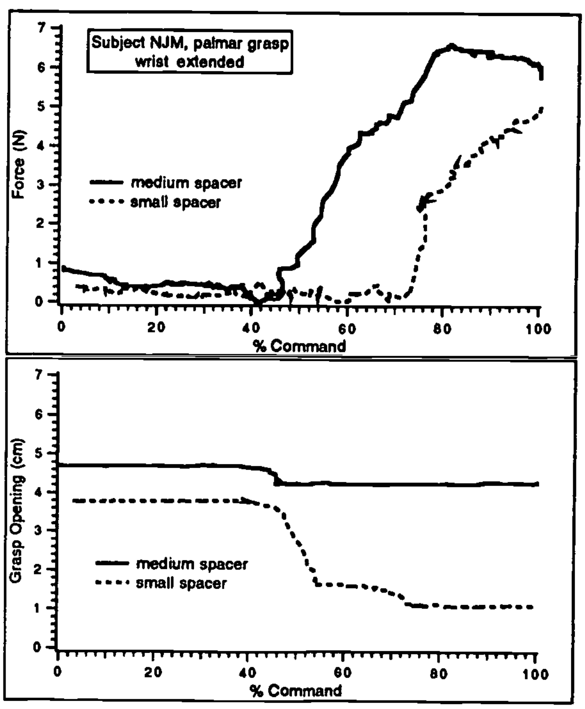

Fig. 4. Input/output data for different spacer sizes

Five of the quadriplegic subjects also performed the control abilities tests. All five subjects had smaller tracking errors when presented with ramp tracks than with step tracks. All five subjects also had smaller tracking errors when using the palmar grasp than when using the lateral grasp.

DISCUSSION

The instrumented hand grasp sensor was used successfully on all six subjects for both palmar grasp and lateral grasp. The experiments with the grasp sensor were performed quickly in an outpatient clinic setting, and were performed on both left- and right-handed subjects. The results of the tracking studies were similar to those obtained with a more complicated and time-intensive experimental set-up [1]. In addition, experiments were able to be performed at different wrist positions since the device was hand held. The instrumented grasp sensor should prove useful in future studies of improvements to the hand grasp neuroprosthesis, such as sensory feedback, closed-loop control, and alternative controller mechanisms.

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STRENGTH ACQUISITION TECHNIQUES IN PARALYZED QUADRICEPS MUSCLE USING FUNCTIONAL ELECTRICAL STIMULATION

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ABSTRACT

Quadriceps strength and fatigue data were collected on three paraplegic individuals using a percutaneous Functional Electrical Stimulation (FES) system. One of the individuals was pre-tested and trained using a protocol of repeated knee extension exercises, one leg at a low resistance and the other leg at a higher resistance. The other two subjects were pre-tested and trained on traditionally accepted protocols of repeated non-loaded contractions. The test leg was trained for two hours longer per day than the non-test leg. The resistance dependant subject showed a 39 percent gain in strength and a 35 percent gain in fatigue resistance from pre-test to post-test in the high resistance leg and an 18 percent strength gain in the low resistance leg but, a 55 percent gain in fatigue resistance from pre-test to post-test. The duration dependant group exhibited no significant strength gain from pre-test to post-test, however, one subject showed a 60 percent increase in fatigue resistance in both the long duration leg and the short duration leg and the other a 25 percent increase in both legs. This supports the belief that strength is best gained by utilizing resistive training as opposed to duration training and that fatigue resistance is best attained through prolonged exercise.

INTRODUCTION

Paraplegic individuals can perform functional tasks with the aid of a percutaneous FES system (1)(2). One of the first and foremost concerns is the amount of time required to build sufficient muscular strength and fatigue resistance to enable the user to execute a functional task such as standing or walking. Building muscle strength and fatigue resistance rapidly is an important concern in the implementation of an FES system. Due to disuse, paralyzed muscles are often weak, even when utilizing artificial stimulation. Exercise programs can be manipulated in several ways to build the strength and fatigue resistance, such as changing the load on the muscle, changing the duration of the activity, and changing the number of exercise sessions. Some of these exercise programs require an unacceptable amount of time to build the muscular strength and endurance. Our goal was to establish an effective exercise program for muscular strength and endurance gain in a reasonable time frame. We are working towards establishing an efficient method for increasing muscle strength and endurance rapidly. This is important as we are presently unable to utilize closed loop methods of control in FES to perform functional tasks and the fact that large amounts of muscle strength is required to safely perform a prolonged FES activity with the onset of muscle fatigue.

METHODS

Muscle strength and endurance data was taken on three paraplegic individuals divided into two groups. One subject was assigned to an exercise protocol that used isokinetic exercise, with one leg exercised at 90 deg/sec and the other leg at 30 deg/sec. The exercise program was executed three times per week for one hour per leg. The other two subjects were assigned to an isometric exercise protocol with the quadriceps muscle exercised fully extended. The distinguishing variable in this group was exercise time. This group also exercised three times per week, one leg was worked for one hour and the other was worked for three hours. The exercise was done with the leg extended to protect the knee joint and bones from excessive torques that might have occurred during isometric exercise performed at angles less than 180 degrees. The maximal strength data was taken on a Cybex II Dynamometer and collected on a portable data collector designed and constructed at the Motion Study Laboratory at the Cleveland VA Medical Center. The pre-test and post-test strength and fatigue data were collected isokinetically at 60 deg/sec. The strength trials were comprised of three contractions lasting one second each with a ten second rest between contractions. The fatigue data were comprised of an hour long trial with quadriceps contractions occurring every three seconds and lasting for one second each. The results of the fatigue tests were normalized for each trial and fatigue was measured as a percentage of the first maximal contraction.

RESULTS

Primary results showed that the resistance dependant subject had greater strength gains faster and had some accompanying gains in muscular endurance while the time dependant group had very small strength gains but showed dramatic gains in muscular endurance (Table 1). The individual using the resistance dependant variable showed a large increase in quadriceps strength, from 51.5 N-m to 71.9 N-m, in the leg exercised at 30 deg/sec compared to the leg exercised at 90 deg/sec which showed a slight increase, from 58.3 N-m to 69.2 N-m. The duration dependant group showed no gains in strength but a large gain in muscular endurance. After the first two minutes of the fatigue experiment the muscle strengths had decreased to a consistent percentage of the first contraction. This was consistent for all of the subjects. After the training period, the duration dependant group showed an increase in fatigue resistance. One subject showed an increase from 30 percent strength after two minutes of exercise to 90 percent strength after two minutes of exercise and the other showed an increase from 55 percent to 80 percent fatigue resistance. The individual trained with the resistance protocol showed an increase from 50 percent fatigue resistance to 85 percent fatigue resistance in the high resistance leg and an increase from 25 percent fatigue resistance to 80 percent fatigue resistance in the low resistance leg. These levels were maintained for one hour.

DISCUSSION

When muscles are exercised there are several ways to increase strength. One way is to increase the load on the muscle and another way is to increase the duration of the exercise (3). Another consideration is the condition of the muscle prior to the onset of exercise. The subject, EB, in the duration dependant group had already participated in the FES research for two years and was already well conditioned. This could explain why we did not see as dramatic a change in fatigue resistance that we saw with subject, DC, and with the lower resistance leg of subject, BK. Previously published papers concerning conditioning of paralyzed muscle using FES stated that prolonged exercise on unloaded muscle produced significant increases in muscle strength. These tests were done stimulating the arm and hand (4). These bouts of exercise lasted up to 8 hours in duration and were commonly done while the user slept. This length of exercise proved to be unreasonable when stimulating the lower extremity for several reasons. First, the lower extremity is comprised of larger muscles and exercise produces large forces and cannot be done comfortably enough for the subject to sleep. Second, exercising the lower extremity uses a large amount of metabolic energy. This causes an increase in heart rate, respiration, and body temperature (5). These factors indicate an alternate method for strength acquisition is desirable. Using a higher load on the muscle builds strength by forcing the muscle to adapt to accommodate the load thus building the strength of the muscle involved. The leg which was exercised at lower resistances showed smaller strength gains due to the fact that smaller adaptations were needed to accommodate the load. In this respect the low resistance leg is much like the duration dependent group. The increase in fatigue resistance can be attributed to the length of exercise being one hour sessions. In the duration dependant group we saw a large increase in fatigue resistance in both legs. The load was easily accommodated by the muscle so adaptation in muscle strength was not needed and did not occur. However, to perform the repeated contractions over an extended period of time, adaptation in fatigue resistance was needed to complete the exercise. The similar gains in fatigue resistance across the subjects leads us to believe that one hour bouts of exercise is sufficient to build fatigue resistance. Another interesting point to note is the similarity of the final fatigue resistances. This occurrence may indicate that there is a finite level of fatigue resistance which can be attained. So, regardless of whether an individual starts at 70 percent fatigue resistance or at 15 percent fatigue resistance they can expect to level out at around 80 to 90 percent. This evidence lends itself to the possibility that the subjects were experiencing specificity of training and that a combination of several different exercise protocols is probably the best direction to take to increase muscular strength and endurance in an acceptable time frame.

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Table 1

		MUSCLE STRENGTH (N-m)		FATIGUE RESISTANCE Normalized Torque	
Subject	**GROUP**	**Pre-Test**	**Post-test**	**. . Pre-Test**	**Post-Test**
EB	Duration Short Leg	135.6	128.8	60	80
EB	Duration Long Leg	142.4	136.0	55	80
DC	Duration Short Leg	46.1	50.2	40	85
DC	Duration Long Leg	32.5	23.1	30	90
BK	Resistance 90 deg/sec	58.3	69.2	25	80
BK	Resistance 30 deg/sec	51.5	71.9	50	85

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VOLITIONAL EXERCISE PLUS ELECTRICAL STIMULATION: SIGNIFICANTLY IMPROVED MUSCLE PERFORMANCE

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ABSTRACT

The purpose of this study was to examine differences in knee extension (KE) muscle performance (MP) between maximal voluntary contraction (MVC), electrical stimulation (ES) alone, and two intensities of ES+MVC (Minimal and Maximum Tolerated). Subjects with intact sensation were tested isometrically and with knee movement (60 Deg/S) on a closed-loop exercise dynamometry and electrical stimulation system. Voluntary exercise resulted in greater KE peak moment and work than neuromuscular electrical stimulation (NMES) alone ($p<.0001$). The addition of ES to MVC improved work performed in isokinetic trials, and Minimal ES + MVC was as effective as Maximal ES + MVC. Minimal ES + MVC resulted in less fatigue than MVC ($p<.0002$). The addition of a second channel of ES resulted in greater peak KE moment in both isometric and isokinetic trials.

BACKGROUND

Neuromuscular electrical stimulation (NMES) can be used to augment muscle performance in patients with musculoskeletal and neuromuscular disorders. There is confusion in the literature, however, in regard to the amount of force and work that can be generated when NMES is employed. Previous reports on the percent of maximum voluntary contraction (MVC) that can be obtained with NMES exercise alone in normal individuals varies from 12 to 92% of MVC [1-4]. The major limiting factor in force production has been the maximum electrical stimulation (ES) intensity tolerated by the subjects, and human subjects are extremely variable in their comfort, or discomfort, during NMES. Most of the previous findings were gathered during isometric exercise and so are not necessarily applicable to isotonic or isokinetic exercise. There is little information on the effectiveness of superimposing NMES on MVC, although some investigators report increased peak force production in small samples of athletes [5].

A better understanding of the effectiveness of NMES on muscle performance in normal, healthy individuals is important to the physical therapy management of patients with intact or impaired sensation. Such an understanding will help to predict how NMES can enhance muscle force production, work performance and fatigue resistance, all of which are clinically relevant measures of muscle function.

The **purpose of this study** was to determine if there were differences in knee extension (KE) muscle performance (peak force generation, work performed and fatigue) between maximal volitional effort, NMES alone and NMES superimposed on maximal volitional effort. Two intensities of ES were tested (maximum tolerated ES and that required to produce 1-2 Nm of knee extension moment) during isometric and isokinetic exercise (60 Deg/S).

METHODS

Subjects: 20 normal subjects (12 women and 8 men, 28.8 ±4.8 years) participated. None of the subjects used NMES for regular exercise.

Instrumentation: Cutaneous electrodes (3x4 inch, PALSFLEX, Axelgaard Mfg, Fallbrook, CA) were used for open loop NMES exercise (asymmetrical biphasic, 300 uS, 33 pps). NMES was provided by a modular stimulator, plug-in board in an IBM PC/AT. KE exercise (concentric isokinetic and isometric) was controlled by the LidoActive dynamometer (Loredan Biomedical, Davis, CA). Analog signals from the LidoActive system were sampled by the IBM for angular position, velocity and moment. Calibration, gravity compensation and all data acquisition were performed by the IBM system. An auditory beep (headphones) cued the subject to perform the next KE in voluntary trials, and onset of ES cued the subject in all NMES + MVC trials. The electrical stimulator was programmed to allow the limb to return to 80 degrees of flexion and then immediately stimulate again. No rest interval was allowed between repetitions in either mode of exercise.

Procedure: Each subject attended 8 KE exercise sessions. During each session, a 40 repetition, maximal KE protocol was performed. Isokinetic MVC was performed first and the order of subsequent trials varied. The knee angle at which peak KE moment was generated by isokinetic MVC (60 Deg/S) was used for isometric exercise trials. Subjects were not permitted to use their hands or arms during the exercise. Single and dual channel NMES recruitment curves were performed immediately prior to each NMES trial. The current intensity at which the subject first noted stimulation was recorded as their threshold, and the minimal level of ES used for testing (ie sensory +) was the intensity (mA) required to produce 1-2 Nm of KE moment (ie 1-2 Nm compared to a range of 100-400 Nm voluntary KE). Maximum tolerable level was that intensity (mA) deemed "maximal comfortable or tolerable" by the subject during the recruitment curve. The following four exercise modes were performed isometrically and at 60 Deg/S: MVC; Maximum tolerable NMES alone; Minimal ES + MVC; and Maximum tolerable ES + MVC.

The LidoActive isometric measurement mode was not used. Instead, the system was held in a "ready" state and isometric data were gathered by the IBM system. Peak moment and work performed (where applicable) were documented for each KE repetition and performance data were plotted by a custom software protocol (Fig. 1). Each subjects maximum effort was accepted as MVC based upon previous documentation of the repeatability of isokinetic fatigue curves [6]. A high intensity burst of high frequency stimulation was not employed for the purpose of documenting recruitment because of the discomfort involved and the potential influence on subject compliance and performance in the ensuing data collection periods [7].

RESULTS

Voluntary exercise resulted in greater KE peak moment and work than NMES alone ($p<.0001$) (Fig 1-2). NMES alone produced 29.9 $\pm$ 27.3% of isometric MVC and 28.8 $\pm$ 16.3% of isokinetic MVC. Higher KE peak moments and lower rates of fatigue were observed in isometric trials (MVC, Minimal ES+MVC and Maximum ES+MVC) when compared to isokinetic trials ($p<.001$-$p<.0001$) (Fig2-3). The addition of NMES to MVC significantly improved the work performed when compared to MVC ($p<.001$). Minimal ES+MVC resulted in similar increases to that achieved with Maximum ES+MVC ($p>.39$) (Fig 1 and 4). Minimal ES+MVC resulted in significantly less fatigue than MVC ($p<.0002$) (Fig 1 and 4). The addition of a second channel of stimulation resulted in significant gains in peak KE moment in both isometric and isokinetic exercise trials ($p<.001$).

Voluntary Only

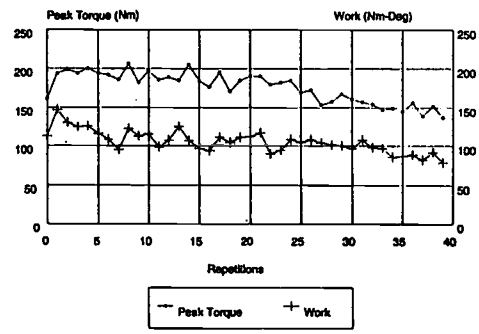
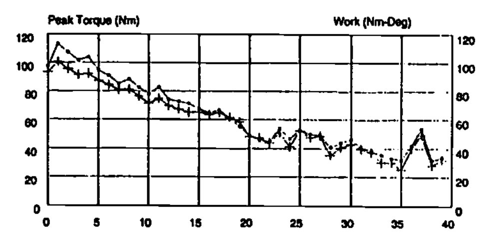


Fig. 1. Comparison of peak KE moment performed in isokinetic MVC, NMES alone and Minimal ES+MVC in one subject. A: Peak Moment and Work for each of 40 MVC KE (60 Deg/S).

Electrical Stimulation Only

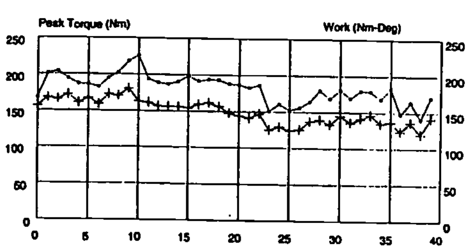
Maximum Tolerated Stimulation Level



B: Maximal NMES alone (60 Deg/S, open-loop, Ch1:150 mA/Ch2:130 mA). Peak KE moment and work are less than MVC and rate of fatigue is greater than MVC.

Voluntary + Electrical Stimulation

Sensory Level Stimulation



C: Minimal ES+MVC (60 Deg/S, open-loop, Ch1:25mA/Ch2:31mA). Peak KE moment is slightly higher than MVC, work is greater than MVC and the rate of fatigue is less than MVC.

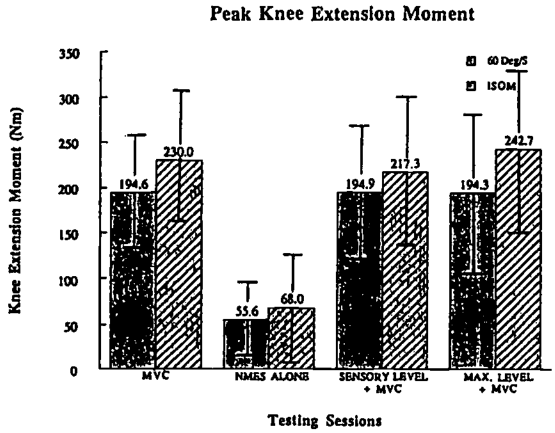


Fig. 2. A comparison of peak KE moment (Nm) among the 8 test conditions (n=20). MVC>NMES alone (60 Deg/S and Isometric), p<.0001. Higher peak KE measured in isometric trials versus 60 Deg/S (p<.001-.0001) except in NMES alone.

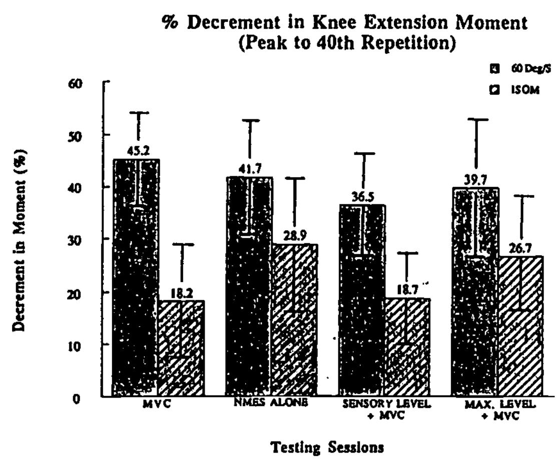


Fig. 3. Fatigue (% decrement in KE moment over 40 repetitions) was less in Isometric than in 60 Deg/S (n=20, p<.001). Minimal ES+MVC resulted in less fatigue than MVC (p<.0002).

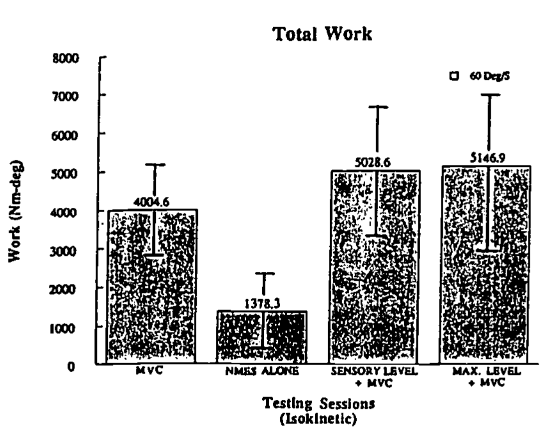


Fig 4. NMES + MVC significantly improved work performance over MVC alone (p<.0001).

CONCLUSION

NMES KE exercise, alone, is not equivalent to voluntary KE exercise. It is inappropriate to claim that NMES KE is a passive exercise that provides the benefits of regular exercise. NMES KE alone, however, can be a useful substitute for the patient with inadequate quadriceps when volitional recovery is incomplete. Although Minimal ES+MVC did not result in greater peak KE moments in all subjects, it was effective in increasing work performance and delaying fatigue during the 40 repetition test protocol. These findings have immediate application for the enhancement of motor performance, as an integral part of physical therapy, in patients with neuromuscular and musculoskeletal disorders. The enhancement of muscle performance, including work and fatigue resistance, in subjects with intact sensation offers support for the therapeutic use of cutaneous NMES as a rehabilitation tool, as well as a neural prosthetic.

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THE REHABILITATION OF GAIT AFTER STROKE: A COMPARISON BETWEEN CONVENTIONAL THERAPY AND MULTICHANNEL FUNCTIONAL ELECTRICAL STIMULATION THERAPY

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Abstract - A comparative study aimed to evaluate effects of conventional therapy vs. multichannel functional electrical stimulation (MFES) therapy was carried out on the group of 20 hemiplegic patients. According to the Latin square experimental design each patient served as his own control. Differences between therapies were evaluated using the Fugl-Meyer test for scoring physical status of the patient, and by measuring stride time, length, and velocity. The statistical analysis showed significantly greater improvement in gait during the therapy with MFES.

INTRODUCTION

Since its introduction functional electrical stimulation has been widely accepted in the gait correction of paretic patients (1,2). Later the MFES was introduced in the therapy of gait (3,4). The authors tried to demonstrate long-term effects in modifying and improving the existing gait pattern by means of MFES in ambulatory patients. The results presented were somehow vague partially due to large inter-patient variance in stimulated and control group and partially due to the fact that the effects, which were quite clear at the beginning, showed the tendency to fade away in period of one year. On that basis it was suggested, that MFES should be used in non-ambulatory patients with the purpose to induce the gait (5). The pilot study (5) showed that those severely involved hemiplegic patients, who could start with gait training, should be able to reach more or less independent gait in approximately three weeks of daily therapy with MFES. The study however showed no comparative value of the proposed therapy with respect to the existing conventional therapeutic methods.

EXPERIMENTAL DESIGN

In the classical experimental model we have a two-group design in which a subject selected from the desired population is randomly assigned to one of two treatment procedures. One group is usually an experimental group and the other is a control group. Obtaining an adequate sample size in the classical model is a problem in clinical research. The effectiveness can be further limited by vagueness or imprecision of sample definition. For reliable results a large number of subjects participating in the study is required. Increased precision in matching groups for all relevant variables at the beginning of the study may be a solution. The risk is still present that with a misfortunate selection of subjects a sample may be biased toward producing false negative or false positive findings since balancing all important variables, even if known, would be difficult. Therefore, a replicated 2 x 2 Latin square experimental design was employed in our study (6). By that, both tested treatments were performed on each subject, however, in different subjects with the reversed sequence of the treatments. Thus 10 replicated 2 x 2 Latin squares were formed as shown in Table 1. The Latin square design provides a method for controlling individual differences among subjects, which enables us to reduce the number of participating subjects. However, deep and relatively more complex statistical analysis is required to obtain valid results (7).

Square	Subjects in square	Period P1	Period P2
1	S1	a	b
	S2	b	a
2	S1	a	b
	S2	b	a
.	..	.	.
.	..	.	.
10	S1	a	b
	S2	b	a

Table 1: Experimental design of 10 replicated Latin squares where S1 and S2 are subjects within each square, P1 and P2 are the first and second period, and a and b are two different therapeutic methods.

INSTRUMENTATION

The stimulator used for MFES in the study contained six independent, galvanically separated channels with intermittent pulses, each optionally triggered by a left or right heel-switch. Stimulation during one gait cycle was timed for each channel by using 16 switches, 8 for the stance phase and 8 for the swing phase. When the switch was on, the stimulation occurred during the selected time interval of the stride phase. These sequences were automatically adjusted to the walking rate of the patient.

At the beginning, at the switchover of therapies and at the end of treatment period stride time, stride length and stride velocity of the patient's gait were measured. Temporal parameters were measured with special ground reaction measuring shoes and the distance parameters were measured by a potentiometer with a wheel and fishing line. Both were connected to a PC for data acquisition. Over 30 steps were performed during each measurement and the average value of the measured parameters was calculated. In addition to these quantitative measurements the physical performance status in each subject was evaluated according to the Fugl-Meyer evaluation scale (8). The result of this evaluation is a numerical score, where higher scores represent better performance. These evaluations were performed in all patients by the same therapist.

SUBJECTS

Hemiplegic patients secondary to stroke, who were unable to walk, but could stand with or without the assistance of a therapist, were candidates for our program. Subjects were selected on the basis of neurological, internist, physiatric and psychological examinations. The level and nature of the lesion were considered together with compensation of the cardiovascular system, passive range of motion in lower extremity joints, proprioception, response of individual muscle groups to MFES, intactness of skin, and peripheral circulation. In addition to the patient's informed consent, an adequate psychosocial condition, communicativeness, and motivation were also required. Patients with contraindications (e.g. demand pacemaker, pain, dizziness, changes on skin, rejection of MFES) were immediately excluded from the study.

Twenty hemiplegic patients were randomly assigned to two groups. The first group comprised 5 male and 5 female subjects (2 left and 8 right hemiplegics), with a mean age of 53.4 years (standard deviation 11.5 years); the second group comprised 6 male and 4 female subjects (9 left and 1 right hemiplegics), with a mean age of 59.1 years (std. dev. 9.0 years). The first group started with the program on an average 116 days after onset (std. dev. 66 days) and the second group started 104 days after onset (std. dev. 62 days). The whole program lasted for approximately 6 weeks (3 weeks each period).

TREATMENT

In program referred to as "conventional treatment" the patient received a normal program of rehabilitation, which, with minor variations is widely used and accepted in most of the rehabilitation institutions. It includes physical exercises, Bobath training, massage, thermal therapy, biofeedback therapy, gait training, etc.

In "MFES therapy" the patient received MFES, beside the program of conventional therapy. However, it was reduced and adjusted not to overexert the patient. Trains of 0 to 120 V stimulation pulses of 30 Hz frequency and 200 μs pulse duration were applied in most cases to the common peroneal nerve for ankle dorsal flexion, to the soleus muscle for plantar flexion, to the quadriceps muscle for knee extension, to hamstring muscles for knee flexion, to glutæus maximus for hip extension, and to triceps brachii for reciprocal arm swing during the swing phase of the ipsilateral leg. Exact stimulation sites were determined by cyclic stimulation. With the patient in a seated or prone position, the electrodes were shifted along each muscle selected for stimulation until an optimal response was obtained. When the sites were determined, they were marked on the skin with semi-permanent ink. Amplitude was raised until the functional response was satisfactory, or below the pain threshold if the contraction was not satisfactory. The stimulation sequence was determined for each subject, starting with an initial pattern and modifying it during the first couple of stimulation sessions until optimal gait was achieved. The subjects walked on a 100 m walkway. They started with the support of the therapist covering a shorter distance, repeating it after the rest period. The initial distance depended on the subject's ability, or it was determined by the subject's physician. In the course of treatment, the distance was gradually increased up to 600 m per session. Each subject participated in one session per day, five times a week. No therapy was conducted on Saturdays and Sundays. On the day of measurement the patient received no therapy before the measurement, to avoid possible carry-over effects of the therapy.

Source	SS	DF	F	α
Period	270	1	4.81	0.041
Therapy	980	1	17.44	0.001
Square	602	9	1.19	0.361
Subj. within sq.	410	10	0.73	0.691
Ther. int. side	15	1	0.27	0.616
Total	2276	22	1.84	0.101
Error	955	17		

Table 2: ANOVA of Fugl-Meyer scores, where SS means Sum of Squares, DF Degrees of Freedom, F the statistical F-ratio and α confidence level according to F and DF. The observed variances are: between periods, therapies, squares, subjects within a square, and between therapies in interaction with side of impairment.

RESULTS

The analysis of variance (ANOVA) according to our experimental design was used to analyse the measurement results. The difference between the values of observed parameter at the beginning and end of period was regarded as the improvement during that period. The parameters analysed were: Fugl-Meyer test score, mean stride cadence (1/stride time), mean stride length and mean gait velocity. ANOVA of the Fugl-Meyer scores is presented in Table 2. The results show that period had a significant influence to the outcome of therapy. The therapy applied first, irrespectively of its kind, was more effective than the one applied second at a confidence level of $\alpha < 0.05$ (5%). The difference between the effects of each therapy was

also highly significant. The MFES therapy is more effective than conventional therapy at a confidence level of $\alpha < 0.001$ (0.1%). The other two hypotheses: improvements between Latin squares are equal and improvements between subjects within Latin square are equal can not be rejected on the statistically significant level. It indicates that the distribution of subjects among squares was homogeneous. This emphasises even more the credibility of the results, while the differences between therapies could not be attributed to weird subjects distribution. In experiments with relatively small number of participating subjects it is very likely that misfortunate random grouping of subjects may bias results toward one of the treatments. There was a possibility that such case happened in our experiment. Namely in one group there were 2 left and 8 right hemiplegic patients and in the other group there were 9 left and 1 right hemiplegic patient. According to the possibility that side of impairment could affect the results of therapy the improvement due to interaction of therapy and side of impairment was also tested. The ANOVA showed no statistically significant difference ($\alpha = 0.19$), which means that side of impairment had no significant impact on the results of therapy. The ANOVA was performed in the same manner also for the other three measured gait parameters. The results and conclusions thus obtained were almost identical to those presented above.
During these analyses a question arose, whether the improvement in Fugl-Meyer score, which evaluates the integral state of the patient, could be replaced or is identical to improvement in measured gait parameters, which are more related to the patient's gait. Correlation coefficients were calculated between improvements in Fugl-Meyer score, stride time, stride length, stride velocity. The correlation of those parameters with age of the patient and with time from the onset to the beginning of therapy was also calculated. The results are presented on the Table 3.

	T	L	V	Age	T_{ons}
FM	0.53	0.57	0.59	-0.29	-0.19
T	x	0.65	0.81	-0.17	0.01
L		x	0.93	-0.28	-0.13
V	symmetrical		x	-0.18	-0.15

Table 3: Correlation coefficients between Fugl-Meyer test (FM), stride time (T), stride length (L), stride velocity (V), age and time between the onset and beginning of therapy (T_{ons}).

The results show relatively poor correlation between Fugl-Meyer test and gait parameters ($r = 0.53 \div 0.59$), however, as expected the gait parameters were better correlated to each other($r = 0.65 \div 0.93$). None of these parameters is correlated to the age of the patient or to the time between onset and beginning of therapy.

CONCLUSIONS

The presented comparative study showed, that therapy with MFES is superior to the conventional therapeutic methods in early stage of the rehabilitation of gait in hemiplegic patients. The MFES should be used as an integral part of the complex rehabilitation programme. The best results were achieved in the early phase, when the patient started with gait training. MFES should be applied until the patient is not capable to participate in programme, where simpler MFES devices, passive orthoses or any other assistive devices are used.

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PARAPLEGIC WALKING WITH FUNCTIONAL NEURAL STIMULATION

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ABSTRACT

Twenty-five paraplegic subjects have been fitted with the VA-CWRU functional neuromuscular stimulation (FNS) walking system. Twenty four were able to stand and twelve were able to walk with a walker. A maximum walking distance of 1100m was achieved without stopping at speeds up to 1.0m/sec. The subjects experienced increased muscle size, reduced osteoporosis, and increased cardiovascular fitness. The main problem with the standing system was inability to achieve prolonged hands-free standing. These problems were worst in those unable to assume a standing C posture. Walking revealed initial hyperactivity for the first 60m followed by a fairly stable swing for about half an hour. After about 300m, additional hip instability was noted. Major deviations were noted from normal in the kinematics of the hip, pelvis, and trunk. Timing of stimulation was found to be critical for energy-efficient walking. Current subjects use an average of 28ml of O_2kg/min compared with normal walking which requires 8ml of O_2/kg/min at an average speed of 0.5m/sec.

INTRODUCTION

Spinal cord injury often results in muscle paralysis and inability to walk. If the spinal cord below the level of injury remains intact, it is usually possible to achieve limb movement by applying FNS to peripheral nerves either directly [Marsolais 1988] or through the skin [Kralj 1989]. Our group has been developing a system for walking in paraplegia using percutaneous electrodes implanted into muscles. The system allows stimulation of individual muscles and provides the capacity to synthesize movements approximating the appearance of normal walking. While such walking is not yet practical for daily use, it has the potential to be developed into a functional technique [Marsolais 1992]. Computer simulation using a biomechanical model of paraplegic walking indicated that unsupported, normal-speed paraplegic walking with electrical stimulation was feasible [Yamaguchi 1990].

METHODS

Twenty-five paraplegic subjects (T5-T11) have been fitted with the FNS system. Three types of electrodes were used to deliver stimuli with microprocessor controlled 48-channel stimulator [Borges 1989] to the paralyzed muscles. Percutaneous intramuscular wire electrodes [Scheiner 1990] were implanted in all major muscles controlling the trunk, hips, knees, and ankles. The subfascial patch electrode [Scheiner 1992] also implanted was used for stimulation of posterior thigh and back muscles.

Template stimulation patterns were generated based on normal electromyographic activity. The pattern was tailored to each individual according to approximate recruitment properties including twitch threshold, functional movement, and maximal pulse width (PW) output. Maximal PW was determined for each electrode by using manual muscle testing to identify a value at which no adjacent muscles were recruited. The PW was limited to 150μs to be within the range of safe intramuscular stimulation [Mortimer 1980]. Submaximal values were used to modulate muscle activation level and to provide joint stiffness during coactivation. The base interpulse interval (IPI) was 60ms and when additional strength was required, the IPI was reduced to 30ms. The specific changes in the stimulation pattern were related to the subject's impression and to the programmer's visual assessment of the walk as recorded on video tape. A video-based Motion Analysis (MA) system was used for quantification of gait. Force sensing resistors (FSRs) were used to determine gait events and to initiate the next step.

Based on our experience of limb movements generated by muscle stimulation, we developed a set of programming rules to provide a structure for tuning paraplegic walking. The process tended to normalize the appearance of the walking and to minimize the subject's effort. Criteria for normal appearance included minimal lateral sway, smooth motions during swing, step symmetry, minimal knee hyperextension during heel strike and weight acceptance, and erect posture. Achieving minimal subject effort required reducing medio-lateral instability of the hip/trunk, good forward progression (speed), and reduced upper body support. Additional support for balance was provided by the walker and the therapist.

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RESULTS AND DISCUSSION

Of the twenty-five subjects all but one, who failed to develop sufficient quadriceps strength, were able to stand, 3 stepped within parallel bars, 12 walked with a walker, 8 climbed stairs, and two are currently in the conditioning phase (TABLE 1).

A 48-channel FNS assisted walking was achieved in the paraplegic individual for a maximum distance of 1100m (without stopping), using a rolling walker and standby assist, up to speeds of 1m/sec. An 8-channel system was necessary for standing and transfers. Our experience implementing multi-channel FNS systems in paraplegics has shown that use of such a system is safe from developing compartment syndrome [Doyle 1992], will prevent muscle atrophy [Marsolais 1988], reduce osteoporosis [Lew 1987] and improve cardiovascular fitness [Edwards 1990].

A repeatable motion for walking was accomplished in well conditioned individuals with open-loop control. During the first few minutes of walking an exaggerated swing was observed and progression of the body was good, requiring no assistance. After about 60m the leg swing settled down and was repeatable for the duration of the walk (up to 36min). At the same time, the speed of walking was reduced from 0.8m/s to 0.6m/s as was the step length, the hip extension moment was reduced to 20% of its initial value, and the subject required a forward push for progression. MA data showed the ground reaction vector (GRV) remained in front of the hip and knee for most of the stance phase. This produced flexion moments at the hip resisting the activity of hip extensors rather than adding to the extension. In the normal gait, where the GRV passes behind the hip, it helps bring the body over the stance leg and renew momentum for forward progression. The GRV passing in front of the knee kept the knee in extension producing a compass type of gait which required extra elevation of the center of gravity as the body passed over the stance leg. The progression force was applied by the assistant who walked with the subject holding onto a safety belt. Minimal force in direction of walking was required about the time of the heel strike. After 300m or 10 minutes of walking, additional instability was observed at the hip. This included both adduction/abduction and internal/external rotation. At that time the assistant provided a correcting moment in the frontal plane in addition to forward push for the rest of the walk up to 1000m.

Timing of stimulation was critical to progression during gait. Use of automatic triggering of the next step by an appropriate delay in the stimulation pattern, determined through trial and error, produced much better forward progression than could be achieved by using the FSR's threshold under the heel to continue with the next step. We found that FSRs induced too much delay (due to sensor response and foot positioning) in the gait cycle and that during automatic triggering a deference in the delay as short as 20ms produced major changes in progression of gait.

Synchronization of stimulation with MA data revealed unnecessary activation of antagonist muscle groups (posterior portion of adductor magnus and gluteus medius) during stance phase, poor timing of plantar flexors (gastrocnemius) for push-off and excessive swing due to knee extensor (quadriceps) activation while hip flexion stimulation (iliopsoas) was being reduced. These anomalies resulted in excessive wasteful metabolic energy consumption. In addition, we found that weight acceptance was irregular and delayed into mid stance as compared to normals; and that the most weight bearing on the arms occurred during the beginning and the end of stance when hip extensors and plantar flexors are the most active. These are the muscle groups responsible for moving the body forward. We found that elimination of either hip extensors or plantar flexors reduced the speed of walking. Depending on the strength of individual hip extensors, the speed was reduced by as much as half by removing hamstrings from the stimulation pattern.

Paraplegic subjects during FNS walking used an average of 28 ml of O_2/kg/min compared with normal walking which requires 8ml of O_2/kg/min at an average speed of 0.5 m/sec. A paraplegic subject supine on a mat using walking stimulation program consumed 20ml of O_2/kg/min. An additional 8ml of O_2/kg/min during walking was therefore used by the upper extremity and trunk muscles under voluntary control to compensate for instabilities of the FNS gait, in particular those at the hip, pelvis, and trunk. The maximum aerobic capacity of subjects in FNS program was determined to be 36ml of O_2/kg/min [Edwards 1990].

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Table 1. Subjects Involved in the FNS Walking Project

Case	Injury Level	Age	Time Post njury (mos)	Time in Study (mos)	Function Achieved
1	T-8/9	23	5	79	S,W,St
2	T-5	23	65	43	S,W,St
3	T-6	26	6	20	S,Step
4	T-8/9	32	20	17	S
5	T-10	32	61	6	S
6	T-4	21	50	44	S,W,St
7	T-11	27	40	51	S,W,St
8*	T-9	38	56	119	S,W,St
9	T-7	31	32	26	S.W
10*	T-5/6	18	11	88	S,W,St
11*	T-7	23	7	115	S,W,St
12	T-7	40	36	54	S
13	T-5-7	43	132	26	S
14	T-7/8	31	5	28	S,W
15*	T-7	27	23	44	S,W,St
16*	T-7	29	82	22	S,Step
17	T-8	27	26	12	S,Step
18	T-8	20	5	5	S
19*	T-6	39	24	7	S,W
20	T-7	30	22	8	S
21*	T-10	33	23	13	S,W
22*	T-7/8	24	23	6	C
23	T-8	28	75	10	I
24*	T-7	33	200	4	C
25	T-11/12	36	36	12	S

I-insufficient strength, C-conditioning, S-standing, Step-stepping, W-walking, St-stair climbing
*-active in the project

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SIG-11
Computer Applications

"BEST" PRODUCTS FOR COMPUTER ACCESS

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Evansville, IN

ABSTRACT

To keep current with the rapid influx of information on electronic barrier eliminators, everyone interested in alternate computer access must be informed consumers. This paper discusses the Best Switch Interface (BSI) and BESTKeys, two partial keyboard emulating interfaces (KEIs) available from BEST (Boston Educational Systems and Technology, Inc.), selected as the most appropriate KEIs for a therapeutic preschool, running on a tight budget with a donated IBM AT and DOS based software. Additionally this paper compares the BSI and BESTKeys with nine features to consider when selecting a KEI.

BACKGROUND

Educators, service providers, and people with disabilities have worked for years to eliminate physical barriers, never dreaming that electronic barriers would be created when consumers with disabilities found standard keyboards difficult or impossible to activate. Alternate input devices were designed to delete electronic barriers by working in the place of the keyboard (1). While some products can be interfaced directly to the computer without requiring another piece of equipment, other alternate input products require attachment to a KEI. Cabled between the input device and computer, the KEI permits the alternate input device to act in place of the standard computer keyboard (2).

Emulators have come far since 1981 when the choices for KEIs were few. In the late 1980s, the golden age of emulators, there were over 20 KEIs available from more than 10 companies. Since that time, some KEI businesses have gone bankrupt while other companies have dropped KEI products for more sophisticated versions. The selection of the best KEI match between the device and user is crucial. Some features to consider when selecting a KEI include: 1) true versus partial emulation, 2) mouse emulation, 3) support of access options, 4) support of computer platforms, 5) support of operating systems, 6) transparency, 7) modular versus system, 8) health of the company, and 9) price (3).

The acronym "KEI" brings to mind the idea of a true KEI. A true KEI takes the place of a complete keyboard while a partial KEI takes care of some but not all keyboard functions. Someone using the whole computer keyboard with letters, numbers, function keys, etc. will need a true KEI. There are times, however, when a partial emulator will work well. For example, an early childhood classroom utilizing software that requires the use of the spacebar, enter, and escape keys could use a partial KEI while an accountant who has a diagnosis of spinal cord injury at the C_4 level, resulting in quadriplegia, would need a true KEI to write reports, manage the budget, and complete other office operations.

The capability of emulating a mouse is important when considering a KEI for someone using software applications that incorporate the operations of keyboard and a pointing system (mouse, trackball, or another device). Mouse emulation may not be necessary for a person who utilizes software that uses the keyboard only and does not have pointing system requirements.

KEIs vary in the support of access options. Many KEI devices permit a variety of direct (e.g., alternate keyboards) and nondirect selection methods (scanning and morse code). A few KEIs allow ASCII input, permitting the interfacing of certain augmentative communication devices.

Support of computer platforms is another feature to consider when choosing a KEI. Some KEIs are designed for specific computer systems; others may be interfaced to several different computer platforms with the appropriate cables. KEIs also differ in degree of transparency. Transparency is the ease of using standard computer applications. Some KEI devices are completely transparent, allowing the operation of all standard computer applications. Other KEIs, designed to load software in order to run the KEI prior to the running of the standard software, may not permit full software operation.

Another feature for consideration in KEI selection is modular versus system. Ideal as center assessment devices, some KEIs (system devices) have a variety of access modes. The user who may need only scanning must purchase all the access methods in a system type of device while with modular KEIs, the user may purchase only the access mode he or she needs.

Health of company, judged by years in existence, visibility as exhibitors at technology conferences, support services, soft money, etc. is another feature to consider when choosing a KEI. With new companies popping up and other businesses folding in the rapidly changing assistive technology field, dealing with healthy companies both before and after the sale is critical.

Price is yet another feature for consideration in the purchase of a KEI. Some users have seemingly endless funds while other buyers may have budgets that limit the amount of their purchases. For some purchasers, $50.00 may be the only difference of being able to fund a KEI or not.

OBJECTIVE

For this paper, the objective is to select the most appropriate KEI for a therapeutic preschool, running on a tight budget with a donated IBM AT and DOS based software.

APPROACH

In looking at the many KEIs available, the field was narrowed by selecting four key KEI characteristics:

1. The KEI must work with the IBM platform and DOS.
2. The KEI must be easy to use.
3. The KEI must have the capability of being assigned one to eight keys/key combinations.
4. The KEI must be inexpensive (under $250.00).

RESULTS

Two devices, both from Boston Educational Systems and Technology, Inc. (BEST), were found to match the four key characteristics. With products designed for IBM computer and true compatibles, BEST, located at 63 Forest Street, Chestnut Hill, MA 02167, 617-277-0179, has two devices: the BEST Switch Interface (BSI) and BESTKeys. In addition to the hardware aspect, each product has software (BSI programs for the BSI, and Emulation Program for BESTKeys) which must be loaded before running the device. The software allows the user to customize the standard keyboard in three ways: 1) to act as a Shift, Alt, or Ctrl key, 2) to be any sequence of standard keys (e.g., a macro), or 3) to act as an audible alarm.

At $125.00, the BSI is one of the least expensive KEIs currently available. With the capability of being assigned one to three keyboard customization combinations, the BSI is a cable with a connector to a computer's serial or parallel port (buyer's choice) at one end and a round (2¾ inches in diameter) switch adapter with three miniphono jacks at the other end (Figure 1). The user may use one to three standard switches with miniphono plugs.

Allowing up to eight keyboard customization combinations, BESTKeys costs $195.00. BESTKeys consists of a cable with a connector to a computer's serial or parallel port (buyer's choice) at one end and at the other end, the BESTKeys Keyboard, a wedge shaped box (7¾ long by 12¼ wide with a depth of one inch at the end closest to the user and 2 inches farthest from the user). The BESTKeys keyboard has eight two-inch square keys, arranged in two rows of four keys with ⅝ between the keys (Figure 2). The design of the BESTKeys Keyboard provides a built-in keyguard in separating the keys. To prevent slippage of the BESTKeys Keyboard on a surface, the device has two clear suction cup "feet" (1¾ in diameter) on the rear of the box.

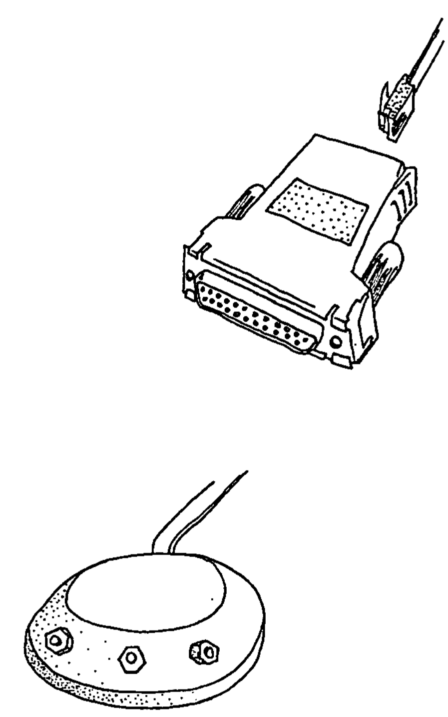

Figure 1. BEST Switch Interface (BSI)

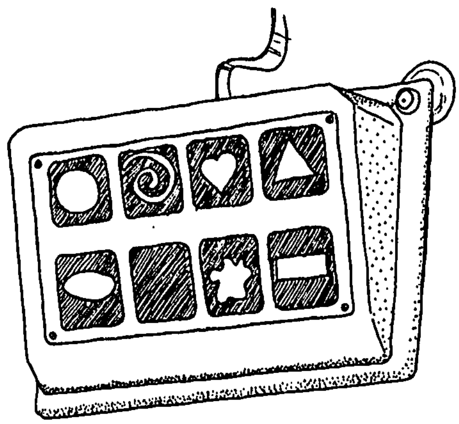

Figure 2. BESTKeys

DISCUSSION

For the therapeutic preschool, the best KEI match is one of the two BEST products. Both devices match the four key KEI characteristics of working with IBM platform and DOS, being easy to use, having the capability of being assigned one to eight keys/key combinations, and being priced under $250.00. To compare the BSI and BESTKeys with the KEI features discussed earlier, both products are partial KEIs without mouse emulation that permit direct selection (one to three switches with the BSI and up to eight keys in the BESTKeys), work on the IBM platform with DOS, are semi-transparent and modular. Although BEST is a new company, it seems healthy and with both devices under $200.00, the products are certainly reasonably priced

One suggestion to enhance the marketing of BESTKeys is to add eight miniphono plugs so the user may have the availability of using one to eight switches or the BESTKeys keyboard.

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Scanning Assessment Tool
Assessing Selection Control Techniques

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Abstract

People who use scanning for accessing assistive technology may not have been adequately assessed for the scanning mode (automatic, inverse, or step) they can control most accurately. Thus, their access to the assistive technology devices may be slower than necessary and cause fatigue. The Scanning Assessment Tool software program helps to evaluate scanning ability. This software program collects data on accuracy rate, switch used, switch position, and speed. This information can be used during assessments to compare effectiveness across scanning modes, switches, switch positions, and to document changes.

Introduction

Persons with muscle incoordination due to cerebral palsy or other impairments use assistive technology to increase their independence. Even with assistive devices some individuals still have difficulty controlling their movements to access keyboards that are connected to assistive technology devices. A more appropriate access method may be scanning.

Scanning involves the ability to press one switch reliably to operate computers and assistive devices for communication, writing, mobility, and/or environmental controls. Three scanning modes form the foundation of scanning; automatic, inverse, and step. In Automatic Scanning the switch is pressed and the cursor advances across the items automatically. When the cursor highligths the desired item, the switch is pressed again to indicate the desired item. For Inverse Scanning the cursor only advances while the switch is being pressed. The desired item is indicated by releasing the switch. The item that the cursor indicates when the switch is released is the item presented. In Step Scanning: the switch is pressed successively to advance the cursor item to item. When the cursor highligths the desired item, the user releases the switch. The absence of a switch press is the signal that a selection has been made[1].

When compared to direct selection, scanning is usually slower[2 3]. Because scanning is a slower method of interfacing with assistive technology every effort must be made to insure the user is using the scanning mode that will be most efficient.

Assessment

When evaluating persons who are potential candidates for scanning, it is necessary to establish their efficiency using each mode (automatic, inverse and step). After mode efficiency has been established, scanning patterns (row-column scanning, directed scanning, group-item scanning) can be evaluated to improve speed of scanning. In the assessment process selecting the appropriate mode comes after the switch and switch position have been established and before the user begins examining scanning patterns.

Unfortunately, many times the scanning mode that may be most efficient for the user is not recommended. There are several reasons for this. First, persons who use scanning are not adequately assessed for the scanning mode they can most adequately operate. By this time in the assessment, the user may have fatigued or the allotted time for the assessment is nearly over. Since other major decisions have been made, such as seating issues, which switch, and position of the switch, the scanning mode may not be addressed. Many times, the recommendation will be to use automatic scanning due to fatigue of the client, time constraints of the assessment team and lack of a tool to help in assessing this area. Although automatic scanning is the mode most often seen in commercially available software[4,5], preliminary findings show that youths with spastic cerebral palsy perform most poorly using this mode[6]. Thus, persons who use scanning may be employing the mode that is least effective for them. Second, the cursor speed must be slow enough for the user to control the scan mode adequately. Using an inappropriate mode necessitates decreasing cursor speed to allow for accuracy. When using the appropriate scanning mode, the speed can be increased. Users are more efficient and faster using the proper mode. Third, when users make an error they must wait for the cursor to continue on its path of scanning all the items and then return to the item the user originally wanted; a time consuming process. Error rate can be decreased when user access the mode over which they have the most control. Thus, they scan more rapidly.

Scanning Assessment Tool

The Scanning Assessment Tool is a software program that provides numerical information that evaluators can use when recommending scanning modes. It is written in Hypercard, runs on a Macintosh computer. It requires a Macintosh computer with 512x342 or greater screen resolution, a hard disk, HyperCard 2.1 or higher, System 7.0 or higher, a Macintosh Switch Interface or Ke:nx (available through Don Johnston Developmental Equipment), and the switches the evaluator wishes to examine with the user. The switch plugs into the Macintosh Switch Interface or Ke:nx and the interface plugs into the computer.

The Scanning Assessment Tool has two components; a practice component and a test component. The practice component displays three boxes on the computer screen, with a smiling face in one of the boxes. Three boxes are the minimum necessary to allow practice without an undue amount of waiting while the cursor completes the scanning path. Users press their switch indicating they are ready to begin. The cursor, a shaded square, moves from one box to the next traveling across all three boxes. The subject presses the switch when the cursor moves to the box containing the smiling face. Cursor speed adjustment and learning how to use the scanning mode takes place during the practice component.

During the test component, the evaluator chooses between using three six or nine boxes. Figure 1 displays how the screen appears with six boxes presented for testing.

For step mode, the cursor moves as fast at the user can press the switch. The acceptance time controls how fast scanning can proceed, that is; how long the cursor highlights an item before it is chosen as the desired one. If the acceptance time is set for a half-second, the user must press the switch within that time to move it to the next item, otherwise the item that the cursor is highlighting will be accepted as the item of choice.

The software collects data on accuracy and error scores, in which box the error was made, speed, mode, the time when subjects press their switch, switch being used, and switch position. The data can be express in graph or table form. Either form can be printed out for a hard copy to be kept in the users file and to visually demonstrate the user's performance using each mode.

Summary

The Scanning Assessment Tool can potentially affect the ability of persons with cerebral palsy and others who have muscle incoordination to effectively use assistive technology devices. It provides evaluators with numerical and visual data to help make scanning mode recommendations. The software can be used to keep records of improvements or changes in scanning ability. Both of these factors help ensure that persons using scanning will be using the interface method they are best able to control when using writing, augmentative communication and other assistive devices.

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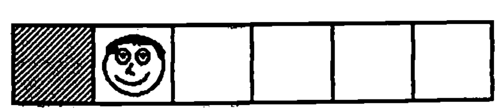
Figure 1.



SHIFTING PRIORITIES IN DEVELOPMENT OF AN ABLEDATA CD-ROM

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Abstract

Macro International recently developed a DOS/Windows version of ABLEDATA to be distributed on CD-ROM. Throughout the initial development process, the development team operated under programming constraints and assumptions about database programming that ultimately proved to be counterproductive to utilizing the capabilities of CD-ROM technology. This paper discusses the development process from the project's inception and identifies the solutions that the development team used to produce a user-friendly version of ABLEDATA for DOS and Windows applications.

Background/Statement of the Problem

As a major government contractor, Macro International has had extensive experience in software development. In October, 1993 Macro International Inc. produced its first CD-ROM computer software product, a DOS/Windows version of ABLEDATA, a database of more than 19,000 assistive devices. As part of its contractual obligation to the U.S. Department of Education, Macro is committed to distributing a DOS/Windows version of ABLEDATA on CD-ROM to ABLEDATA users throughout the country. Although the Trace Center had developed both a Macintosh version of ABLEDATA (HyperAbledata) and a DOS version of ABLEDATA (DosAbledata) with the previous ABLEDATA contractor, Newington Childrens' Hospital, the programming for those versions of ABLEDATA was not paid for by ABLEDATA contract funding. Consequently, in order to meet the contractual obligations for a CD-ROM version of ABLEDATA once the contract was moved to Macro, Macro found itself in the position of developing a CD-ROM version of ABLEDATA "from the ground up."

Approach

As technology evolves, certain truisms emerge regarding how to organize data most effectively. These truisms turn into "rules" that then are applied toward future development. However, when developing new computer applications for any medium, a development team often must forget old theories and begin a new line of thinking in order to develop the most effective method of delivering information to the end user. Rather than accepting the old rules as givens, it is important to re-think what the ultimate objectives are and then address those issues. Macro's programming team faced this very issue during the development of a DOS/Windows version of ABLEDATA on CD-ROM.

One of the basic principles of programmers is that it is important to maximize the amount of information and minimize the space on the disk used for that information. This was one of the underlying assumptions with which Macro's programmers approached the entire development process.

ABLEDATA is designed to serve the information needs of persons with disabilities and rehabilitation professionals. Thus, in addition to providing access to the database product data files through both DOS and Windows applications, the Macro software has graphics allowing the user to view a picture of the product before requesting information from the manufacturer.

The Windows application was written in Asymetrix's ToolBook. The DOS application was written in Computer Associates's Clipper 5.1. Both of the versions rely on identical dBase III+ formatted files.

The beta version of the ABLEDATA CD-ROM was shipped to beta users in October 1993. The early comments from the users indicated that they felt the software was "extremely slow." It became clear that, if this database was to be used on a regular basis by consumers and service providers, the basic issue of speed needed to be addressed.

During the process of development of the beta version, the principles to which we had become accustomed while developing software had led us to believe that our first priority was to reduce the amount of data that would be stored to the user's hard drive. At this early development stage, we considered the second priority to be the speed of the application. However, if potential users would not use the database because of the length of time required to search the database, clearly those priorities needed to be re-evaluated.

The first step in fixing the problem was to ignore the current version and "rethink" the retrieval logic of the software. It is difficult to not let an earlier version bias the thinking for fear of rewriting the entire application.

Macro formed a development team to review the retrieval logic around which the software was built. The team spent time trying to optimize the program logic, but it takes a long time to search 19,000 records regardless of the speed of the searching mechanism. It quickly became apparent that the retrieval component of the software could not be optimized any further .

It was during these development meetings that the suggestion was made by one member of the staff to just store the retrieval information to the CD-ROM. Since we were only using about 20% of the available storage capacity of the CD-ROM, every possible search combination could conceivably be stored directly on the CD-ROM to minimize the time required by the user to search the database. Instead of the software calculating the records to display and storing the information to a data file on the local hard drive, the CD-ROM would be used to store the retrieval information.

Implications

By incorporating these simple changes, the development team was able not only to increase the speed of the application dramatically, but also to reduce the amount of disk space required on the user's hard drive.

Discussion

In developing applications for a CD-ROM, as opposed to applications for hard disk storage, the principles to which many programmers have become accustomed quickly become obsolete. The primary goal clearly is to get the information to the user in the shortest amount of time. The most abundant resource is the amount of storage a CD-ROM product brings. Therefore, instead of coding intricate file-saving measures into the program, it is considerably more effective - although contrary to programmers' logic - to ship the retrieval information on the CD and spend the development effort getting the information to the user faster.

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ACCESS TO BUSINESS GRAPHICS FOR BLIND PEOPLE

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ABSTRACT

Optical character recognition (OCR) software can provide blind persons' access to printed textual information. However, such software generally ignores graphics, which often provide information vital to understanding the document. In this paper, we report on a dialogue system which converts such graphics into an equivalent numeric form and subsequently outputs it to a blind person in an appropriate manner.

INTRODUCTION

Blind persons today have access to text-based information by scanning it into a computer and then presenting it to the (blind) user using and speech synthesis-software. Similarly, text on a computer screen can be presented to the blind person using conventional screen-reader-software.

Recently, attempts have been made to provide access to text in graphical user interfaces (GUIs) [1]. This is necessary because most new software is developed for GUIs, which generally are used by sighted persons. However, a graphical screen is much more difficult to translate into a form appropriate for blind users. Modern OCR-software as well as GUI-screen-readers give the blind user a reasonably complete access to textual information contained in the paper/screen. Graphical information such as charts and drawings is ignored completely. This is an increasingly important problem since modern computer-applications as well as printed materials are significantly enhanced with graphics.

One aspect of this problem was addressed in [2]: Access to model-based photorealistic images. The work on this class of graphics showed that the "model" of the graphics is needed for presentation to blind people.

In this paper, we report on our work to make business graphics, which are often found in newspapers, books and computer applications accessible to blind persons. Often they contain an important part of the information of the document. Many of these business graphics are augmented with ornaments or pictorial information which is added to make the chart easier or at least more fun to read for sighted persons. These ornaments, however, aggravate the work of automatic recognition to an extend that makes it impossible for the computer to achieve the work by itself (see for example Fig. 1).

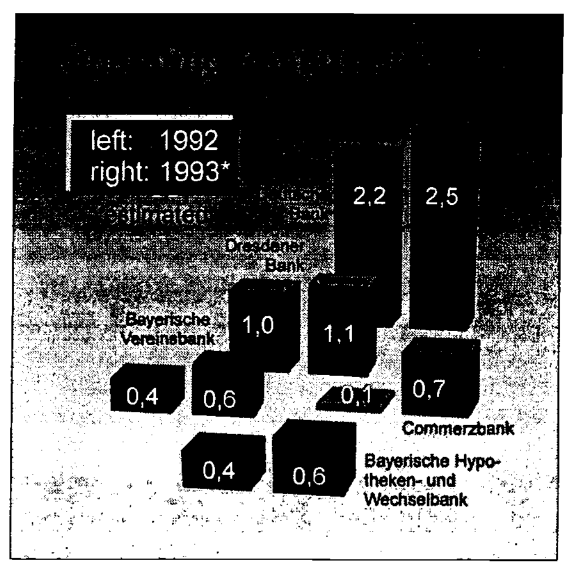

Fig. 1: typical diagram

Our approach is an interactive one: To get the figures on which the business graphics is based, we exploit the human capability to interpret this kind of graphics.

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A "user-exploiting" modelling process gives results in the figures behind the diagram. We call these figures the model of the chart. The approach is described in more detail in the following (second) part of this paper.

This model, basically a table, must then be conveyed to the blind user. This second component of our system uses speech, sound and/or tactile output to present the figures in an appropriate way to the blind person. We explain the methodology in the third part of this text.

The fourth (and last) part gives a conclusion and discusses work still to be done to give blind people full access to (business) graphics intended for sighted persons.

TRANSFORMING GRAPHICAL INFORMATION INTO NUMERICAL DATA

Since blind persons cannot grasp diagrams directly, we first have to extract the numerical data on which the graphic is based. This numerical data (a table) will then be presented to the blind user as described later.

We can start with one out of two general situations: (1) If the diagram is included in an electronic document like a text-file in a word-processor, we have to convert the bitmap (if it is represented as one) into a vector-format. This is done using conventional vectorisation-software. (2) If the diagram is presented in paper-form, we first have to scan it in to get the corresponding bitmap. This bitmap will then be treated like the bitmap contained in an electronic document. In both cases, the result is a vector-graphic-file.

This vector-graphic forms the basis for our modelling process which can be described as follows:

The system which we implemented is a highly interactive one.

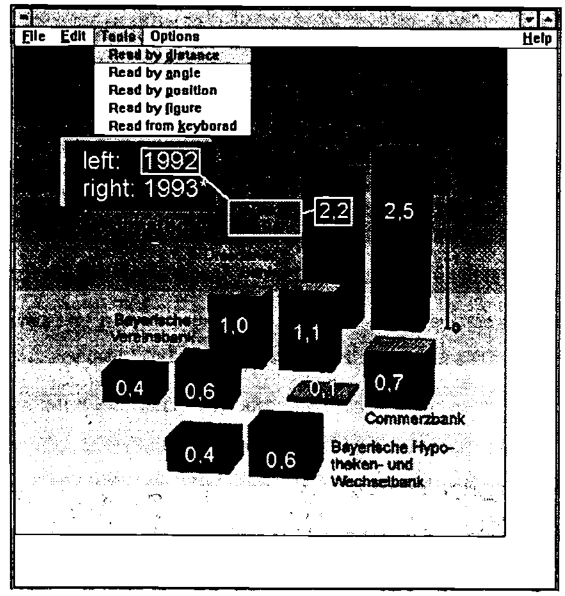

Fig. 2: Screen-dump of the modeller

First, the diagram's type and dimensionality are examined. The diagram can be of line-, bar-, or pie-type (other types are possible). It has two dimensions if each value on the x-axis has one corresponding y-value. If for one x-value more than one y-values exists, the diagram is three-dimensional. While system can find out the diagram's type by it self in most cases, the user often has two set the dimensionality manual since many charts look two-dimensional at the first glance but are in fact three-dimensional,

Next, the user has to set the scale (not needed in pie-charts). If the original diagram has a scale included, this task is easy: The user clicks at the lower and then at the upper end of the scale and defines the resulting line as the scale. The corresponding values can either be determined automatically by reading the values next to the scale's ends or typed in manually.

Now, the table-contents itself must be extracted from the diagram. The user clicks on an x-value (or the corresponding position in the diagram) and then on the associated y-value. This value- pair is now inserted in the table. If the chart is constructed quite simple, the system can now determine the other value-couples from the diagram. Otherwise, the user has to proceed with the procedure as described.

Finally, titles, subtitles, comments and other text present in the diagram are marked and added to the table by the user, possibly supported by the system.

The result of the transformation process is a table which now can be stored in a spreadsheet-format. It can now be presented to the blind user in an appropriate form.

	Deutsche Bank	Dresdner Bank	Bayer. Vbank	Comm.-bank	Bayer. Hyp.
1992	2.2	1.0	0.4	0.1	0.4
1993	2.5	1.1	0.6	0.7	0.6

Fig. 3: Resulting table (column-header edited)

PRESENTING NUMERICAL DATA

While the modelling process is an interactive one with a sighted user, the presentation of the resulting data can be done without any sighted persons help:

The most accurate presentation of numerical data is reading them to the blind person using a speech-synthesiser. This is the method of choice for small tables where precision is required. Taking into account the source of information (a diagram) precision is not necessarily needed nor intended by the author in many cases. Therefor, we provide alternative forms of presentation: Line-charts can be presented acoustically where the frequency of the tone corresponds to the line's course. Here, a logarithmic scale for the frequency is used because the human sense of hearing is more sensitive for changes in low frequencies than in higher ones.

Bar-charts can be presented as tones too, but we provide still another method: Using a 2D-Braille-Display [3], we display the x-value of a value-couple in Braille on the horizontal line and the y-value (the actual "bar") as a bar of raised dots on the vertical Braille-Line. Scanning the x-axis with the cursor-keys, the blind person can now touch the bar's extent and get a fast impression of the value in comparison with other bars. This leads to a method of working similar to the sighted persons' one.

CONCLUSION AND FURTHER WORK

We can envision that for very simple business graphics, the modelling could even be done automatically, while for more complex business graphics, we would like the dialogue with the sighted user to be even shorter.

More methods of presenting numerical data to blind persons are possible but not implemented yet.

ACKNOWLEDGEMENTS

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SCANNING THE WINDOWS DESKTOP WITHOUT MOUSE EMULATION

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ABSTRACT

Accessing a GUI such as Windows by scanning can be difficult and awkward if reliant upon mouse emulation because of the added task of controlling the mouse cursor. An alternate solution of using appropriate keystroke sequences and repeating these under user control has been developed for WiViK® visual keyboard. The result is that the user can either directly select commands from a scanning visual keyboard or initiate a repeating sequence of keys that give the impression that certain window objects (e.g., menus, sizing borders, scroll bars) are scanning. Both the general approach and specific implementations are described here. The outcome is transparent access to a GUI where the entire interface scans.

BACKGROUND AND PROBLEM STATEMENT

A graphical user interface (GUI) such as Microsoft Windows presents unique access problems because of the requirements on the user. Users are expected to use a pointing device to manipulate GUI objects such as icons, windows, menus, buttons, scroll bars, lists, and text. These tasks require continuous pointing and clicking or holding buttons. (Brownlow et al, 1988)

While alternate pointing devices are available, some users cannot control any pointing device. The remaining options for such users are switch-based scanning or encoding, and voice recognition (which is not always feasible). However, providing functional access with these latter options is difficult because they represent binary (on/off) or discrete actions versus continuous actions normally associated with direct manipulation.

The obvious solution is to translate binary/discrete actions into continuous actions by emulating the mouse. However, it is our belief that mouse emulation is an added task layer imposed on users that carries the burden of unnecessary physical, perceptual, and cognitive demands. The user must also deal with two styles of interfaces—a scanning interface and an artificial pointing interface.

Previously, various techniques of manipulating text with a scanning text cursor using repeating keystrokes have been presented (Shein, 1992). This was implemented using WiViK visual keyboard software which allows a user to enter text into any application within the Windows environment. The ideas originally pursued have been expanded for scanning access and applied to accessing the entire desktop and are incorporated in a new product called WiViK 2 Scan. Except for drawing, all GUI tasks can be accomplished without mouse emulation. These ideas and solutions are described here along with specific implementation considerations.

GENERAL APPROACH

The primary design of Microsoft Windows facilitates an alternative to direct manipulation by providing keystroke equivalents for all actions. This capability is exploited in our scanning solution. Tasks that can be accomplished directly with a single command, such as minimizing a window or copying, are available as macro key actions on individual WiViK keys.

Another Windows capability that people who use standard keyboards regularly take advantage of is repeating keys. If able, a person can hold down a key, such as an arrow key, to quickly move through text, or to move or size a window. They can also position their finger directly over a key and repeatedly select it.

With this in mind, support for repeating keystrokes was programmed into WiViK. When keys that perform actions are repeated, the user has the impression that the actions are scanning—windows appear to move on their own by scanning, or menus scan in succession. Users do not have to concern themselves with how to position and direct a pointer, nor do they have to remember keystroke sequences. All keystrokes are hidden beneath a graphical or text label representing the action. This approach is used when the task involves movement (e.g., sizing, positioning, scrolling) rather than single command selection.

The immediate issue is how to stop repeating (or scanning). Since a switch activation is used to select a key, an obvious solution is to use a second switch activation to stop repeating the selected key.

Within WiViK, a repeat structure was added to augment the macro feature and to allow selective repeating keys. The following structure can be used within the definition of a key:

"<BeginRepeat(100)> keystroke <EndRepeat(0)>"

(note: the terms BeginRepeat and EndRepeat may be replaced with the short forms BegR and EndR).

For example, if the keystroke was a <RIGHT> arrow key, the text cursor would scan across letters until the switch is selected.

The repeat rate should be equal to or greater than the scan rate which is set according to the user's ability to react and activate a switch once a target is reached and before advancing to the next. Within WiViK's repeat structure, a percentage factor can be applied to slow down or speed up the repeat rate.

A further enhancement is to embed sequences of repeating keystroke actions within a single visual keyboard macro key. Each repeating action continues until the user indicates stopping with a switch activation, at which time the next action begins.

Sequences of repeating keys are used to scan menus. One key is defined to pop up the first menu then move across menus one at a time. The user indicates a desired menu by stopping the scanning across menus; scanning then begins down that menu. Stopping the scanning at a particular menu item identifies the item which is chosen with a final <ENTER> key:

```
"<ALT><SPACE>"
"<BegR(100)> <RIGHT> <EndR(0)>"
"<BegR(100)> <DOWN> <EndR(0)>"
"<ENTER>"
```

With this strategy, it is necessary provide a method for the user to indicate when they do not want to follow through with the entire sequence. The best approach is to use a second switch as a 'cancel' switch. This is often prescribed to augment single-switch scanning to cancel scanning across an undesired row or from scanning down many rows. If a cancel switch is not provided, the user must go through the sequence of keys at least once. Since the number of scan iterations cannot be known in advance, an automatic cancel feature cannot be provided. A time-out cancel is a possibility but it would need a very long time setting to prevent unintentional activation. The practical solution, but not ideal, is to use the Undo command when forced to make an undesired selection.

Initially, a problem arose when the menu sequence was cancelled—the menu would remain visible. This was unacceptable since it requires the user to explicitly select the <ESC> key twice to hide the menu. Therefore, WiViK was specifically programmed to automatically hide any menus after cancellation. Another situation which required specific programming was cancelling a macro where a <CTRL>, <ALT>, or <SHIFT> key was latched down. WiViK unlatches any of these keys after cancellation.

Three general scanning methods are provided in WiViK 2 Scan: automatic, inverse/step, and directed scanning. These methods are accommodated by repeating keys as follows. In all scan methods an activation of the 'select' switch stops the current repeat loop and advances to the next item in the macro. Activation of the 'cancel' switch stops any repeating and exits the macro without completing any further macro actions. In inverse/step and directed scanning, activation of *any* movement switch (including specific directions) will perform the repeated keystroke once for each activation. For example, if the <RIGHT> arrow is being repeated, the cursor will advance one item (menu, character) for each switch hit. Holding down these switches will perform the repeat loop at the scan rate.

Repeating always proceeds in a forward direction; its order or actions cannot be reversed. This may be confusing for some users if they have a scanning method that involves a reverse switch and they can reverse scanning direction within a WiViK keyboard. A limitation is that the opposite action to a macro sequence of keystrokes is not definable.

SPECIFIC SOLUTIONS

Menus

Menus may be accessed in two ways— as individual commands each defined on specific keys, or in a general scanning approach. The former approach makes the commands immediately visible and is most appropriate for frequently used commands such as cut, copy, paste and undo but is unwieldy for a large set of commands. The latter scanning approach provides access to any menu throughout Windows after selecting one key within WiViK to begin menu scanning. This reduces the required size of the WiViK keyboard.

The specific approach for scanning has been described above. An additional action associated with scanning is automatic linking to a WiViK key page that displays keys to respond to dialog box which typically follow menu commands.

Dialogs

Dialogs appear frequently in a GUI usually in response to a menu command. Users are asked for input usually by selecting buttons, or items from one or more lists. Buttons and lists are usually grouped together logically. Fortunately, there are consistent design rules for dialogs which help access:

- <TAB> always moves focus to the next group, button, or list,
- <ARROWS> always move up and down lists,
- <ENTER> always select the current button with focus, or selects the OK button if no button has focus,
- <ESC> key always cancels a dialog, and
- <SPACEBAR> always toggles a radio button or checkbox.

Knowing these rules, a WiViK key page was designed with repeating keys to provide scanning movement, and single action keys for the discrete commands. Color is used on the keys to identify movement (green) vs. discrete commands (blue).

Moving or Sizing Windows
WiViK makes use of sequencing the obscure keystroke commands that mouse users never consider. To move a window, the user selects a specific movement key (up, down, left, or right) on a WiViK key page of related commands. Behind these keys are macros that begin by entering <ALT> + <SPACE> followed by the letter 'm'. Then, a repeat loop is used to move <UP>, <DOWN>, <LEFT> or <RIGHT>. The user sees the window move itself in scanning steps.

There are eight commands available for sizing a window since each border can move in or out. Each of these commands use macros that begin by entering <ALT> + <SPACE> followed by the letter 's'. Then, <UP>, <DOWN>, <LEFT> or <RIGHT> is entered to identify a border to size. Finally, a repeat loop is used to size the border <LEFT>/<RIGHT>, or <UP>/<DOWN>. The user sees the window sizing itself in scanning steps and stops it at the desired size.

Switching Applications
WiViK makes use of a key combination familiar to 'power' Window users, <ALT>+<TAB>, to switch applications. The user first selects an application switching key. This initiates a macro that begins by latching the <ALT> key followed by repeating the <TAB> key. A small window appears in the middle of the screen with the names and icons of the application displayed one-by-one in a scanning sequence. The user activates the 'select' switch when the desired application name is displayed to switch to it.

Switching between Program Manager Groups
This is similar to switching applications. First, the user selects a switching key. This initiates a macro that begins by latching the <ALT> key followed by repeating the <CTRL> key. Each group window/icon is scanned in succession. The user activates the 'select' switch when the desired window/icon becomes active. When switching between groups the order of icons scanned may not appear to be sequential. This is because of a Windows limitation. Within a group, the user can move between icons using <ARROW> keys.

Scrolling
Scrolling required specific programming to implement because applications do not use consistent keystrokes, if any, to scroll. A pointing device is a necessity. WiViK circumvents this by providing a set of macro functions (e.g., <SCROLLPGUP>) that send the underlying Windows messages to scroll. These functions are used within repeat loops just as if they were keystrokes being repeated. The user selects a desired scrolling action from a key page of related commands (shown graphically) and scolling appears to scan.

Window Control Buttons
Various buttons often perform actions such as minimize, maximize and restore. While it is possible to point to each button in sequence, it is more practical to select the button directly as a key within WiViK since the number of choices is small. The image of the button is copied onto the WiViK key to ease selection.

DISCUSSION

There are a number of advantages to using keystrokes and repeating keystrokes. The first is the number of switch activations to achieve a result is minimized. For example, any menu item may be selected in four switch hits (two to select the menu scanning key, one to choose a menu, and one to select a menu item). Another advantage is that the user focuses attention on the task at hand such as choosing a menu which is being scanned without having to re-focus attention on deciding upon and selecting another key. With every attention shift, there is the potential for error and added cognitive demands as decisions must be made. A third advantage is that access is relatively quick in comparison to driving a mouse cursor about to get to the GUI object and then acting on that object.

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WiViK is a registered trademark of the Hugh MacMillan Rehabilitation Centre

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A COMPARISON OF COMPUTER ACCESS DEVICES FOR PERSONS WITH HIGH LEVEL SPINAL CORD INJURIES

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Abstract

A study to compare consumer preferences of three adaptive computer access devices, a conventional mouthstick, the PRC HeadMaster, and the New Abilities Tongue Touch Control System was implemented with three subjects with high level spinal cord injuries. Subjects used each of the devices for one month to operate a Macintosh computer. Ratings of ease of use, comfort, sensitivity and aesthetics were analyzed. Subjects preferred the mouthstick for ease of use, and the New Abilities system for comfort, sensitivity and aesthetics. A summary of these results is described in this article.

Background

When computers first became a mass-market commodity, access was extremely limited, especially to individuals with disabilities. As adaptive computer access devices were initially developed, consumers with disabilities were often forced to conform themselves and their task repertoires to these few, existing technologies. Now, with the wide variety of access devices on the market, consumers can mix and match to fit their access needs. An understanding of the strengths and limitations of each device, by itself and in conjunction with other devices as part of a reasonable accommodation, is critical if consumers are to make informed purchases. Accordingly, research in the effectiveness of these devices is valuable to consumers, their significant others and members of the assistive technology service delivery team [1,2].

In an effort to develop an evaluation protocol for this type of research, a pilot study was conducted to compare the conventional mouthstick, the Prentke Romich Company (PRC) HeadMaster, and the New Abilities (formerly Zofcom) Tongue-Touch Control System. This article reports on findings related to the preference for computer access as evaluated by three subjects with high-level spinal cord injuries.

Research Question

The qualitative portion of the study explored how each of the three computer access devices compared with the others in regard to perceived comfort, ease of setup, ease of use, sensitivity, and aesthetic value.

Subjects

Subjects with high-level spinal cord injuries and no prior computer experience were sought for this study; however, procuring subjects who lived locally and who were available for a 3-month study proved difficult. Therefore, a convenience sample of 3 subjects was used in this study. The subjects were all male, non service-connected veterans.

Subject 1 was 79 years old at the time of the study and lived with his wife and a live-in nurse. He suffered an incomplete C4 (central cord syndrome) injury four years prior to the study, and had no computer experience. He walked with assistance, but had little use of his arms. He used the computer at a desk which someone rolled him up to in a manual wheelchair.

Subject 2 was 40 years old and lived alone, but had frequent visits from attendants and friends. He had a complete C4,5 injury which occurred 18 years prior to the study. He got out of bed only to take care of his hygiene needs; however, he remained supine in bed during most of the day. He owned an IBM computer which rested on an overbed table, but was very inexperienced with computers in general. During the study, the Macintosh computer sat on this table, and the keyboard was adhered to the table with velcro in such a way that this subject could type with a mouthstick from his bed with minimal strain.

Subject 3 was 44 years old and lived alone, although he too had frequent visits from his attendants and his girlfriend. He had had a complete C4 spinal cord injury eight years prior to the study. He had an IBM computer on a computer desk in his home, and he was very adept at using it with a mouthstick. He had no experience with Macintosh systems, and was excited to learn about it and to use the various access devices.

Study Design

A three-month study was implemented in which each of the three subjects was asked to use a conventional mouthstick (commercial, telescoping, lightweight), a PRC HeadMaster (Macintosh ultrasonic version), and a New Abilities Tongue Touch Control System for one month each. The New Abilities system consisted of a custom-molded retainer with a built-in circuit board. The retainer is inserted in the mouth and is controlled by pressing the tongue against raised buttons on the retainer. These buttons correspond to actions on a LCD display mounted on the wheelchair armrest and connected to the computer. At the time of this study, the New Abilities system was undergoing clinical evaluations as a prototype product, but was available commercially. The purpose of this study was to explore the consumers' ratings of a low technology (mouthstick), high technology commercial (PRC Headmaster), and high technology, new access device just entering the market (New Abilities).

Quantitative data was collected on speed and accuracy of text entry and cursor manipulations across the three input devices. Each subject was asked to spend two hours per day using the word processor and 30 minutes per day playing cursor-driven games. Twice weekly the subjects were evaluated. Data are being analyzed and will be reported in a detailed article [3].

To gather qualitative data, each subject was provided with a notepad on which either the evaluator or designated caretakers were requested to take detailed notes on the performance of the various access devices. After using each of the three devices for one month, each subject was given a post-test in which he was asked to rate each device for ease of use, ease of installation/setup, comfort level, sensitivity level, and aesthetic quality.

Each subject was given a Macintosh computer and access devices which were installed in his home. The evaluator also assisted with adaptations to the subject's environment and seating and positioning. Although each subject was positioned differently, each worked with the evaluator until positioning was optimal given individual constraints and preferences. Since device usage can be influenced by others in the environment, the evaluator also worked with family and attendants to familiarize them with the computer, access devices and troubleshooting techniques. By having the subjects use each of the devices for a one month period, they had the opportunity to determine long-term usability and reliability in the natural context of their homes, in comparison to a one-time computer access evaluation done in a clinic or evaluation center. By so doing, consumers were better able to identify daily needs and determine to what extent each device met those needs.

One week before the study was to start, each subject was familiarized with Macintosh operation. Using the mouthstick to access the keyboard and control the computer, each subject explored two software programs, Macintosh Basics and MacWrite II word processor, and games available to each subject. During this week, the evaluator was available to answer questions. For one subject who required help with remembering commands, the evaluator wrote out procedural notes and adhered them to his monitor for quick reference. At the end of this period, each subject demonstrated an understanding of basic Macintosh functions and the ability to competently execute Macintosh operation functions (e.g.: click, move and drag the cursor, and select items).

Results and Discussion

The general usability ratings of the three input devices are shown in Figure 1. In summary, the mouthstick was rated as superior in its ease of use and setup, but faltered in its aesthetic value. The New Abilities system was preferred for its aesthetics, since once mounted in the mouth, it was invisible to others. This system also caused the least sensitivity problems and was rated as the most comfortable access device. However, this system received the lowest ratings due to its complex installation and high learning curve. The HeadMaster generally fell in between the other devices in most rating areas; however, subjects found the headset to be particularly uncomfortable since it moved out of place and required assistance from others to reposition it, and was made of hard plastic which was not adjustable to the size of the head.

As expected, the different access devices each had their own unique strengths and weaknesses. The

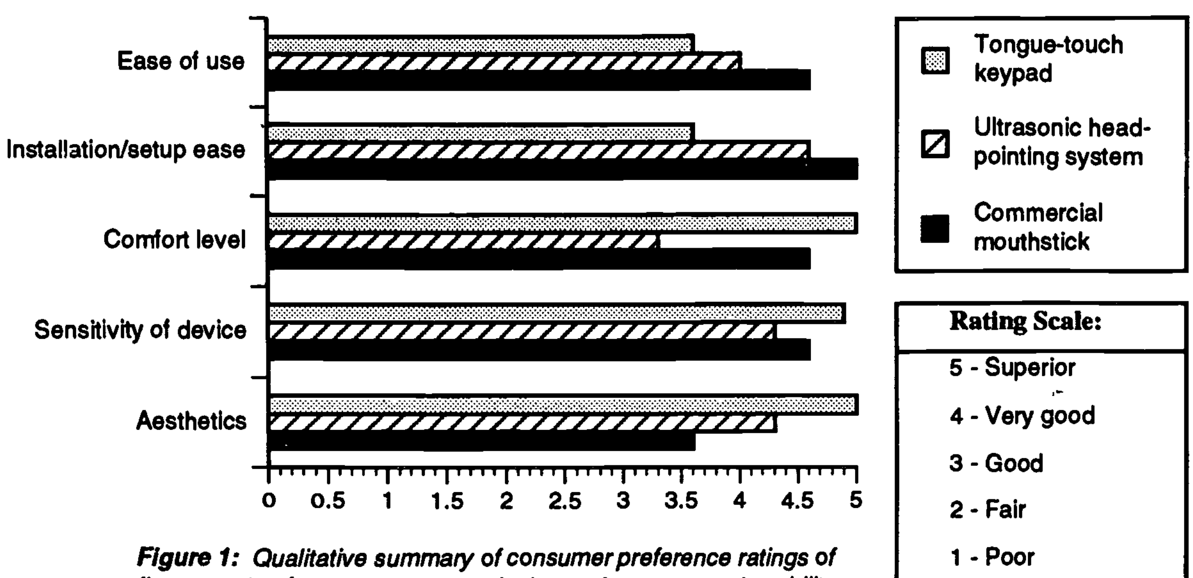

Figure 1: Qualitative summary of consumer preference ratings of five aspects of computer access device performance and usability

mouthstick was highly rated for comfort, value, and reliability. A simple docking station attached to the keyboard gave users independence when using this device. However, the mouthstick did require frequent cleaning, which the subjects were unable to perform independently. Additionally, the keyboard had to be meticulously positioned so that the subject could reach every key on the keyboard. This positioning proved to be a problem for one subject who used his computer while supine in bed. Although not often documented in prior studies, positioning proved to be an influential variable in regard to the qualitative and quantitative ratings given to each of the access devices.

The HeadMaster was rated as moderately comfortable and required no maintenance. Subjects enjoyed the freedom of not having to use the keyboard to utilize the computer, but experienced compatibility and delay problems when using keyboard emulation software. Problems with the HeadMaster also included difficulty talking with the puff tube in the mouth, occasional slippage of the mouthpiece from the user's mouth, and occasional posterior slippage of the headset. The ultrasonic receiver needed frequent repositioning to respond to the input signals from one subject, as his supine position yielded line-of-sight problems which caused the cursor to "float" at times. The headset, as mentioned, was uncomfortable in that it was designed for a person with a fairly round, smaller head and was not flexible in adjusting to individual proportions.

While all three subjects found the New Abilities system the most difficult to use at first, two of the three subjects became adept at using this device after two weeks of practice. All of the subjects found the device to be surprisingly comfortable and the most aesthetically pleasing of all the devices. All three subjects saw this device as potentially valuable since it offered integrated access to the computer, giving control over a power wheelchair and an environmental control unit. Problems included the lack of a docking station for the device which subjects felt would have been useful when talking with someone for an extended period of time, or when eating or drinking. A prototype docking system was fabricated and used to do so. The lengthy initial installation, setup and learning curve required to competently use the device were seen as barriers to efficient use.

Conclusions

Assessment data such as this is important in continuing to produce and provide quality, reliable computer access options to consumers with disabilities. The results of this study point to a preference for integrated systems that allow for universal access to the information technologies which have become part and parcel of our information society. Consumers also preferred access solutions that were compatible with the myriad of assistive technologies that they used on a daily basis, especially environmental control units, phone management systems, and wheelchairs, and that were capable of performing multiple tasks across several contexts, including the home, school, work and community.

Although devices were not paired or mixed within this study, subjects also discussed a preference to mixing and matching low and high technology access software, hardware and devices. For example, after the study, some of the subjects found that they preferred to use the HeadMaster for cursor control and the mouthstick for text entry. Subjects were also introduced to various software programs, including macros, abbreviation expansion, and word prediction, which had the potential to enhance productivity when used in conjunction with other hardware and low technology devices and adaptations.

In terms of the methodology used, this study pointed to the need to document and account for the contributory influence of other variables, especially those related to seating and positioning and environmental setup, within the study. The need for detailed research evaluation protocols and quality study designs which incorporate these factors and allow for multi-site replication of the findings is evident and represents an area of future collaborative work for these authors.

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ALTERNATIVE ACCESS TO ASSISTIVE DEVICES

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ABSTRACT

This paper describes a method that allows the development of multi-modal access systems to computer based assistive devices. The general concept of multi-modal input to computers is introduced and its use for physically impaired users justified. A general method for implementing such access for any computer application has been developed, and it is briefly outlined in the paper.

INTRODUCTION

Computer access for severely physically impaired people usually takes the form of special input devices such as switches, joysticks, head pointers and suck-blow tubes. The rate of data input that can be achieved with these devices is very much lower than that available with conventional input devices such as keyboard and mice. This is due both to the inherently lower bandwidth (information transfer rate) of the devices themselves, and the difficulty that some disabled people have in using these alternative access methods.

Able-bodied people can also have difficulty in accessing computers as well. Most people have five senses: sight, touch, hearing, taste and smell, and a rich and complex motor ability, which includes the abilities to gesture, speak and look. They are largely under-used when we sit down to work with a computer: "the vast majority of us peck at arrays of buttons (called keyboards) and push little boxes (called mice) around on pads"[1]. There is an information bottleneck at the computer interface in that the full communication bandwidth (information transfer rate) available to people is not being utilised.

A MORE NATURAL COMMUNICATION STRATEGY

In real life, normal interpersonal communication is multi-modal - people communicate using a number of different strategies including speech, gesture, pointing, eye-gaze, facial expressions and touch[2]. It is very efficient and natural. By contrast human-computer communication uses only one or two modes (e.g. keyboard) and is inefficient and unnatural. The problem is typically very much greater for disabled users who have a much lower information transfer rate due to their need to use specialised access devices. There is a need for a more natural and expressive form of communication with computers[2]. A multi-modal interface may help provide this. Imagine interacting with a computer that could understand what you said, could interpret your gestures, could follow your eye-gaze, is responsive to your touch and could reply to your enquiries.

As pointed out by Shein, interface technology (for disabled people) is in a rut and still cannot support real time interaction[3]. To overcome this, he advocates that the information bandwidth between a disabled user and a computer should be increased. This can be achieved by using additional input channels including gesture, voice and other aspects of body language. Shein provided a set of guidelines for developers of alternate access systems[4]. In particular he recommends that a wide variety of input devices should be allowed; facilities should be made available to support future input devices; combinations of devices should be supported and multiple input streams should be provided (table 1).

In the context of the able-bodied user, a number of researchers point out the advantages of multi-modal interfaces. Adding new interface devices to computers, as well as adding the capability to support multiple input concurrently, increases the communication bandwidth between the user and computer[2]. Multi-modal input can be more expressive, and it can provide a level of redundancy that helps a program to interpret ambiguous situations. Moreover the simultaneous use of input devices can provide a synergy that makes the whole interface more efficient and expressive than the sum of its parts[2]; multi-modality would greatly increase the efficiency and user-friendliness of current interfaces[5] and communication between the computer and user has been shown to be significantly enhanced when different input modes are simultaneously employed[6]. It can be assumed that these advantages would apply to the disabled user as well.

AN INTERACTION ENVIRONMENT FOR PHYSICALLY DISABLED USERS

The authors are developing a general multi-modal interface for computer systems, with the specific aim of investigating this concept with physically impaired users. The interface is implemented by means of a programming language, which allows software developers to specify how an application is controlled by any number of alternative input devices, allowing alternative modes of access to be easily added to existing or new applications. The language implements a number of the guidelines advocated by Shein (Table 1) as will be described.

The basic concept behind the language is to allow any alternative access system (e.g. single switch, joystick, eyegaze device) to emulate the keyboard and the mouse - standard input devices for most applications. The application developer specifies, using language statements, how the input from the alternative access devices is to be translated into keyboard or mouse commands. When the application is used, the translation is performed automatically, and the application receives input data from any device as if it came from the mouse or keyboard (figure 1). Thus, for example, a switch press made with some appropriate scanning software (the switch and scanning software is treated as a complete input device) would be translated into a keyboard event which is then passed to the application. As far as the application is concerned, the data is being supplied by the keyboard and behaves accordingly. Similarly joystick movements can be translated into mouse movements, and thereafter an application will react to the joystick as it would the standard mouse. More esoteric forms of input can also be used such as eye-gaze or gesture or speech. Thus speech can be used to emulate key-presses; eye-gaze can be used to emulate mouse movements. Support is thereby provided for a wide range of different input devices and future devices can easily be integrated into any application, meeting the requirements given in table 1, entries 1 and 2. The language also provides facilities to define input device combinations (see table 1, entry 3); that is for example speech and joystick input can be combined to provide commands to the application. The remaining two requirements listed in table 1 (entries 4 and 5) will be investigated at a later date.

The system consists of two parts: the first translates groups of user actions made with the alternative input devices into internal symbols and the second translates these symbols into sets of effects (button pushes, slider movements, etc). A hardware dependent software module then converts effects into the necessary events for the particular computer type being used. Currently a module has been implemented to convert effects into X-Events. Thus the language can be used with any computer running the X Window System. It is intended in the future to produce a module for MicroSoft Windows.

The programming language itself consists of a set of statements that allow the programmer to define the various alternative input devices that are to be used; to define the symbols that each device can produce; and to define which group(s) of symbols produce effects. Various conditional expressions can also be attached to effect production. When a program has been written it is compiled and produces the runtime system as output (including the module to turn effects into hardware specific events) which runs in parallel with the application.

A small amount of additional software has to be inserted into the application to allow it to communicate with the alternative devices: thus for existing applications the source code must be available and it has to be recompiled.

The multi-modal interface can also be combined with a plan recognition system. This allows a sequence of user actions to be stored as a set of predefined plans in a plan library. The library can contain many plans, representing tasks that the user wishes to perform within an application. Each incoming action is matched against the plan library and when a plan is unambiguously identified (many plans can be active at once), the system can offer to complete the task, thereby reducing the amount effort required by the user. Plan recognition can be considered as a form of high level prediction. Another aspect of the plan recognition system is that it allows errors in terms of incorrect actions at the interface to be identified and potentially corrected.

DEMONSTRATORS

We plan to develop a number of demonstrator applications which will be used investigate how efficient multi-modal interaction could be for the physically impaired user. As well as providing alternative modes of access, the applications will also contain the high level prediction mechanism (plan recognition) to infer the intentions of the user and to provide assistance in task completion.

CONCLUSIONS

The system outlined in this paper is a novel approach to improving access for physically impaired users of computer systems. The transparent addition of alternative input modes should provide benefits to all computer users - not only users of AAC devices. The use of the multi-modal language and the plan recognition mechanism will be described, and a video of one of the demonstrators in use will be incorporated into the presentation.

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Provide support for a wide range of input devices.
Provide support for future input devices.
Allow input device combinations (combinations of input devices may be more appropriate than a single device).
Allow support for multiple input streams - allowing the application to accept input from more than one source at a time.
Provide input filters - to reduce the effect of unintentional input due to for example tremors, poor targeting or poor operating conditions.

Table 1
Input guidelines for alternate access system developers, from [4].

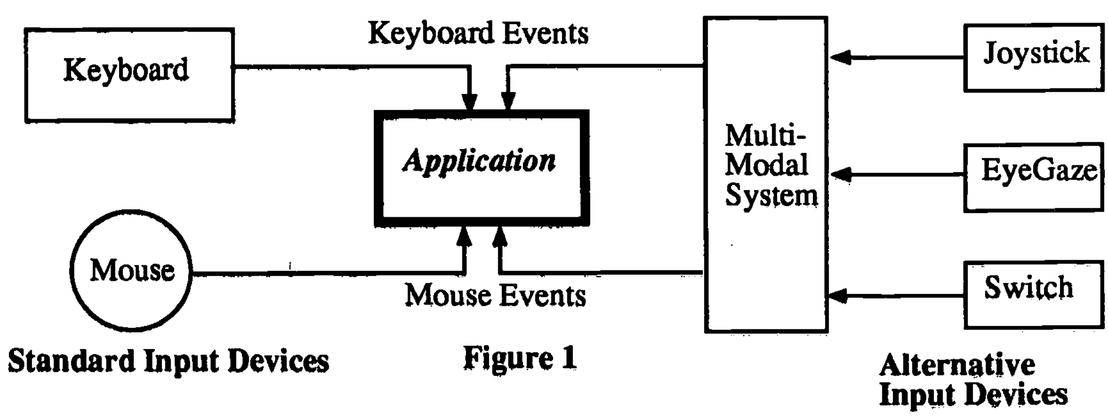

Figure 1

AN INTEGRATED REMOTE VOICE-ACCESSED POINT OF CARE SOLUTION FOR PHARMACY ORDERS

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Abstract

Investigators at the University of Tennessee at Chattanooga (UTC) Advanced Computer Applications Lab (ACAL), in conjunction with personnel from Integrated Voice Solutions, Inc. (IVS) and the U.S. Department of Veterans Affairs (VA), have developed an application which links a hospital information system with a remote workstation that accepts voice commands to operate a system for renewing, canceling and writing prescriptions. This integrated system provides a handicapped physician with a means of writing prescriptions without assistance, enhances his efficiency and the quality of patient care he is able to provide. This report describes the Point of Care Order Solution for Pharmacy Orders (PCOS/PO) and shows how voice technology can be used to enable physically disabled users to access mainstream computer work groups and information networks.

Introduction

Computer voice recognition applications provide a powerful computer access tool for anyone who has repeatable and functional speech control [1].

The PCOS/PO system itself is a product of a research project conducted at the Chattanooga VA Outpatient Clinic (VAOPC). The PCOS/PO system runs on a Prototype Voice Activated (PVA) workstation at the Chattanooga VAOPC. This system is one of several applications of voice/telephone based applications developed by a collaborative industry-government-university team including IVS, UTC and the VA, as well as hospitals such as the University of Tennessee Medical Center and the Siskin Hospital for Physical Rehabilitation [2-10]. The long-term objective of this collaborative research is to enable users with various levels of physical and learning disabilities to access the power of computing through individual computer workstations, electronically networked groups and, eventually, global information networks such as those envisioned by the National Information Infrastructure [11].

Methods

The integrated PCOS/PO system consist of a large hospital information system located in Murfreesboro, Tennessee and a PVA workstation located in Chattanooga, Tennessee. The workstation is connected to the VA's MUMPS-based Decentralized Hospital Computer Programs (DHCP) by a direct serial connection to a local DHCP node through which the main DHCP computer in Murfreesboro is accessed via telephone lines (Figure 1).

Time efficiency for the user is enhanced using memory-resident software coupled with a nightly batch mode interface to DHCP. Through this interface, active prescriptions and patient demographic information is downloaded into the PCOS/PO workstation. The downloaded data provides the physician with information that he would otherwise have to enter himself in order to renew or cancel prescriptions for scheduled patients.

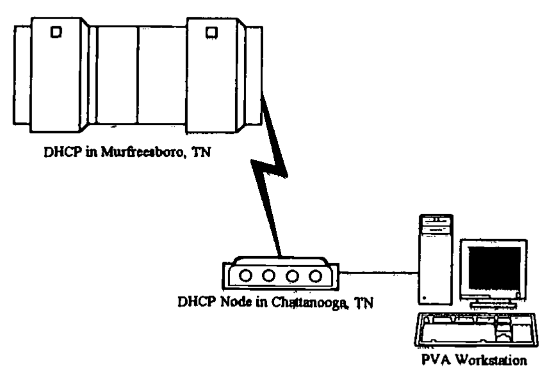

Figure 1 - PCOS/PO System Configuration

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Because of the sensitive nature of the data and the legal signature requirements for prescriptions, several security measures were implemented in PCOS/PO. These include: encryption of sensitive data, limitation of access based on user ID and password validation, and the generation of electronic signatures which validate the data signed as well as identifying the signer. Additional security is provided by the speaker dependent nature of the voice recognition system.

The methods used for interfacing and computer access include keyboard redefinition to provide single-stroke mnemonic keyboard commands, keyboard emulation via voice recognition, and voice command macros which perform several keystrokes with a single voice command.

An IBM-PC compatible microcomputer was selected for the workstation because of its wide usage and the large selection of peripheral devices available. Hardware integration is provided via the PC Bus, the RS232 serial ports, and the parallel printer ports, all readily available in this series of microcomputers.

Voice recognition is provided by the "Dragon Dictate" speech recognition system. The implementation is coded in Clipper 5.01a and is integrated with Datastorm Technologies' ProComm Plus communication software. The ViaCrypt's DigiSig+ 150 electronic signature generator is integrated with the system via a utility which allows other programs to be run from within Clipper applications.

Results

PCOS/PO automatically downloads information from the remotely located DHCP and converts it so that it can be accessed within the application. The system allows the user to renew, cancel and write new prescriptions for patients, sign them electronically and transmit them to the pharmacy to be filled. Access is controlled by a user ID/password verification along with a user verification when prescriptions are transmitted to the pharmacy. To further enhance the security of the system, the keyboard has been disconnected and speaker dependent voice recognition is being used.

The PCOS/PO system automatically provides information about each patient's active prescription if that information has been previously input in to the system either through the DHCP interface or the keyboard/voice interface.

PCOS/PO also maintains a historical record of all actions taken within the system and all prescription information. Searches by pharmacy personnel for old prescription information can easily be performed. This information is then validated when the electronic signature is verified.

All this is done with a few simple keystrokes at the PCOS/PO workstation. Alternatively, PCOS/PO recognizes voice commands to perform the same functions.

Discussion

The PCOS/PO system is ideally suited as an access method to information systems using voice recognition technology. It provides an important link to information stored in the VA's hospital-wide DHCP system. The one critical function, the user validation prior to prescription transmission, as well as all other functions, give the user several options to get the command correct.

PCOS/PO is an important and effective module in the VA's efforts to provide disabled persons with mainstream computer access and an adapted work environment which meets the requirements of the American with Disabilities Act [12]. It is currently being implemented and tested by IVS personnel with the aid of a quadriplegic physician at the Chattanooga VAOPC. There are plans to expand the project to all of the physicians within the clinic so that PCOS/PO will become a general access mainstream application for all physicians, not just the disabled.

This project will move us one step further toward enabling healthcare providers to reap the benefits of accessing global computing and communication networks.

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COMPUTER USE IN TRAINING AND EDUCATION - A META ANALYSIS OF SINGLE SUBJECT DESIGN

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ABSTRACT

Studies employing computer use in teaching and training of individuals with severe disabilities were reviewed and analyzed using quantitative methods. 18 studies which met predetermined criteria were presented and summarized according to the following main variables: design, subjects, treatment, behavior, and dependent measure. Results showed that microcomputers are most often chosen for teaching computer technology to individuals with disabilities. The meta-analysis also showed that computers were used across a large range of ages, abilities, and needs. The techniques were generally effective in improving student performance on task. Studies comparing print-based with computer-based strategies were found to be equally effective.

Background

Computers have become part of the school curricula in most elementary and secondary school settings in the past decade (6, 9, 11, 12, 14). Computer use as an instructional tool has emerged as a trend in the school settings in several curricula areas (7). School curricula involving computer-assisted-instruction (CAI) and computer-based instruction (CBI) are implemented for direct student interaction. Computer-managed-instruction (CMI) is used to assist the teacher in the classroom (6).

The rapid advancement of software and hardware is turning the use of computers to a feasible, manageable component of today's research (3). As schools are using computers in growing numbers in the elementary and the secondary school settings, the evaluation of the use of computers in the classroom setting is becoming an important topic (9, 14). This evaluation should be implemented in research and in systematic reviews of the currently available research studies (13).

The need for an analytic synthesis of the available studies is especially important for students with severe disabilities. The individualized advantage and the nonlinear ability of the computer as well as the ability to record responses accurately, to store information and to provide individualized planned instruction are qualities important especially in the area of single subject design (1). However, evaluation of the current research is needed. A meat-analysis provides a systematic review of the literature and examines the separate and combined effects of different variables within the same investigation (2).

Several meta-analyses syntheses have evaluated the effectiveness of CAI in group design (4, 5, 6, 7, 8, 9, 11, 14). These meta-analyses have concluded that CAI is more effective than conventional instruction for increasing students' achievements. However, no systematic synthesis of current research has been identified for the area of computer use in single subject research design in general and with disabled population in particular. This study provides a systematic review in single subject design with disabled population. The purpose of this study is to analyze and synthesize the research to evaluate the effectiveness of instructional computers in education and training within the area of single subject design research for individuals with severe disabilities.

Method

A meta-analytic approach was used to review and analyze the studies. Research studies were located using an objective, replicable search process, studies were coded and analyzed using predefined criteria. The literature research included articles published between January 1980 and December 1993. The search included all journals known to have contributions in the areas of CAI and single subject design research for subjects with severe disabilities. The search included four methods of retrieval: (a) a computerized literature search for the appropriate years using several databases, (b) a systematic search of all subject indexes and titles, (c) a hand search of major journals related to the criteria areas, and (d) an ancestry search of the bibliographies and references of all appropriate articles to retrieve additional articles.

Forty journals were searched. Articles were included in the study if they met the predetermined criteria: (a) publication in a peer-reviewed journal between January of 1980 and December of 1993

(b) a single subject design research study; (c) computer use in training or teaching; (d) subjects were diagnosed as having a severe disability; (e) graphed outcomes in a time series format; two additional criteria were implemented for statistical calculations, (f) a baseline had to be present; and (g) baseline had no floor or ceiling effects (respectively to decrease or increase of intended behavior).

After concluding the search process, articles were read and coded using a two-step coding process. **Step I** included 8 variables developed to assist in the process of inclusion in the narrative and the analytic sections of the study. **Step II** included a detailed coding system which included a coding form and a coding manual developed to establish consistent values of the variables presented in the studies.

The outcome of step I resulted in 18 articles identified and met the criteria for inclusion in the narrative section of the study. Fifteen studies were included after meeting the criteria for inclusion in the analytic section. Four articles were excluded from the analytic section. The cause for exclusion was lack of baseline data. Two calculation methods were used: (a) a vote count and (b) a process of analytic quantitative method of review was based on the percent of nonoverlapping data (PND) as proposed by Scruggs et al., (1987).

Results

Analytic results present data from 47 subjects taken from 14 studies. All other count data is represented from 67 subjects, all taken from 18 single subject design research studies. Of the 18 studies, 90% used microcomputers as their chosen computer hardware. Of all the studies examined in this review, only one used CBI, 3 reported results from CMI, while the majority of the instructional programs, 67% (12/18) involved CAI. Two of the studies involved an assessment process.

Results indicate that of the 14 studies which reported the software type used for teaching, 43% (6/14) implemented the program using drill and practice, 35% (5/14) used a tutorial, 7% (1/14) used games and 15% (2/14) used simulation. Of 18 studies in the vote count which included 49 cases, 40 showed positive effects for computer use. Four of the studies did report any effect, and 5 did not indicate any results for effectiveness. Thus, on the basis of vote count, computers are effective in influencing the educational outcomes of individuals with disabilities. Only 5 of the studies included comparisons between print-based instruction and computer instruction. Of the 16 cases reported in those 5 studies, 37.5% (6/16) reported superiority for the computer instruction, 37.5% (6/16) reported traditional instruction superiority and 25% (4/16) reported no difference. Computers were found to show positive effects as an educational and training tool for Individuals with severe disabilities. The limited number of cases which compared traditional with computer instruction prevent the ability to draw any conclusions. Additionally the ambiguous results prevent even to draw any inferences. Further research comparing these two methods of instruction should be implemented. Results indicate that microcomputers were the preferred instructional tool for implementing the different software programs. The Apple computer and mainly AppleII was the computer most often used for teaching and training using computer technology in special education. This might result from the large number of Apple computers available to date in the school system. Additionally most of the software used was a drill and practice software. This outcome is compatible with the earlier review studies evaluating group design computer instruction in education and training.

A large variety of skills are used for teaching and training with the assistance of computers. Computers were used to assist teachers while working with students with severe handicaps. CMI was implemented successfully while applying a prompt system with students, for data collection and for observer training. These positive results attest to the large potential variety computers can provide to the teacher and the trainer in the field. The techniques used in the studies were generally effective in improving the students performance on the tasks. The skills students were trained and taught proved to be very different consisting from scanning to word recognition and math facts. The review also shows that computers were used in a large range of ages, abilities, and needs. However, descriptions of several procedures were often inadequate.

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MODIFIED SUPER NINTENDO CONTROLLER

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Abstract

A standard Super Nintendo game controller was modified for Jerry, a 12 year-old male diagnosed with cerebral palsy. An interface was fabricated to facilitate switch access to all twelve Super Nintendo game functions. Jerry accesses four game functions at a time with head movements that activate four switches mounted on his wheelchair. Minimal instruction was required for the adapted version of the game because of Jerry's previous experience using head-activated switches for navigation of his wheelchair and control of his speech communication device.

Background

This project was initiated through a special undergraduate occupational therapy course in vocational and pre-vocational job accommodation. The course introduces students to the provisions of the ADA, principles of ergonomics and universal design, and the process of job accommodation. Students are assigned a semester-long project, which involves working with an individual who is in a vocational or pre-vocational setting and needs accommodation services. Project assignments require students to develop a plan for intervention strategies and assistive devices that will maximize the working efficiency of the individual with whom the student team is working.

Jerry is a twelve year-old male diagnosed with cerebral palsy. He has limited upper and lower extremity movement due to muscle spasticity. Jerry utilizes three head-controlled switches to independently drive his wheelchair and operate external technology. He uses a lever switch to operate several assistive devices including an Apple II GS Computer, a Light Talker communication device, and an environmental control unit that operates television and VCR functions. He utilizes a leaf switch to toggle between forward and reverse operations of his power chair. A switch-control joystick facilitates forward/reverse, right and left navigation of his power chair.

Objective

To fulfill Jerry's need for leisure activities, his parents contacted our Department to obtain assistance with modifications that would allow Jerry to be an active participant in the operation of his Super Nintendo video game system.

Approach

A search was conducted to investigate commercially available controllers that Jerry could potentially operate. Several adapted Nintendo controllers were found, however none were compatible with Super Nintendo.

A standard Super Nintendo controller includes a total of twelve switch buttons (See Figure 1), however most Super Nintendo games require the user to access only 3 or 4 of the controller functions. Nonetheless, our objective was to make all 12 button functions accessible.

We disassembled a standard Super Nintendo controller and discovered that the only possible wiring points were directly on the printed circuit board. The printed circuit board "traces" were clearly labeled to correspond to the 12 button functions, which enabled us to solder 13 connecting wires (12 function wires and 1 ground wire) to the printed circuit board. The twelve function wires were soldered to twelve "mini phone jacks" (Radio Shack part #274-251) that were mounted to an experimenter box (Radio Shack part #270-233). Figure 2 shows the external view of the experimenter box; the labeled letters correspond to the twelve individual Super Nintendo controller functions. The printed circuit board was then mounted inside the experimenter box. The standard connection from the printed circuit board to the Super Nintendo unit was not altered.

Most of the Super Nintendo games require the user to access only three or four of the controller functions. Our initial objective was to make four game functions available to Jerry, utilizing four switch sites that Jerry was already using for other activities (i.e. mobility, computer access, environmental controls). As a participant, Jerry uses his leaf switch to "start" the game and his lever switch to "select" specific options of the game. Two pedal switches (Radio Shack part #44-610) were mounted to the right and left head rests for the purpose of controlling two specific game actions (i.e. right and left "punch" of the boxing game).

Results/Discussion

Minimal time was required to teach Jerry how to operate his video system. Jerry was already very skilled in the operation of his wheelchair controls and was immediately successful with the switch operation of the games.

After one month, Jerry is very proficient with the use of four actions per game. Our plans include expansion of Jerry's functional capabilities with the Super Nintendo games utilizing the switch control joystick on his power chair. Jerry's parents have noticed Jerry's increased enthusiasm, self-confidence and self-esteem. Jerry's access to Super Nintendo allows him normalized interaction with his peers and provides him with an age appropriate leisure activity. The game activities promote skills that will ultimately assist him with multi-switch control of computers, communication devices, and environmental control units.

In the short term, this adaptation enables Jerry to assume the role of active participant in a highly popular form of entertainment activity for children and adolescents.

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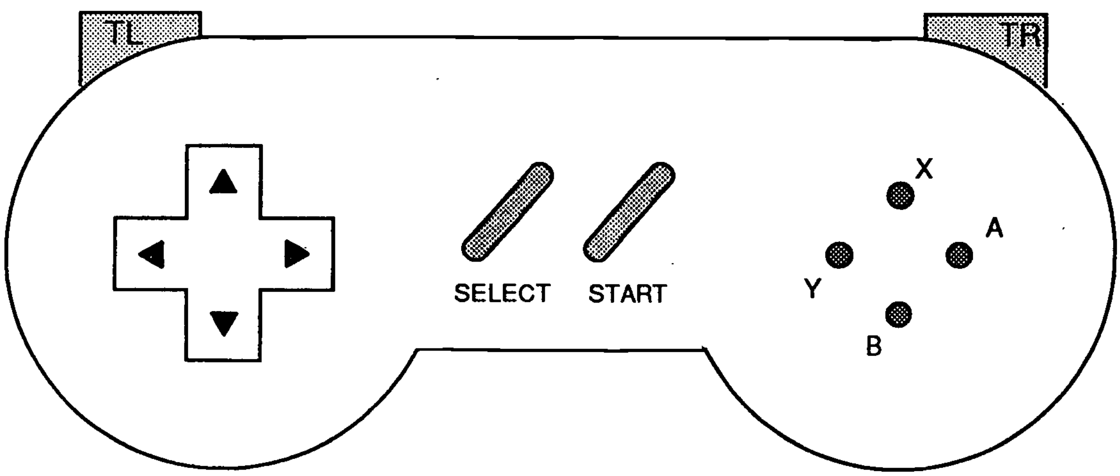

Figure 1: Standard Super Nintendo Controller

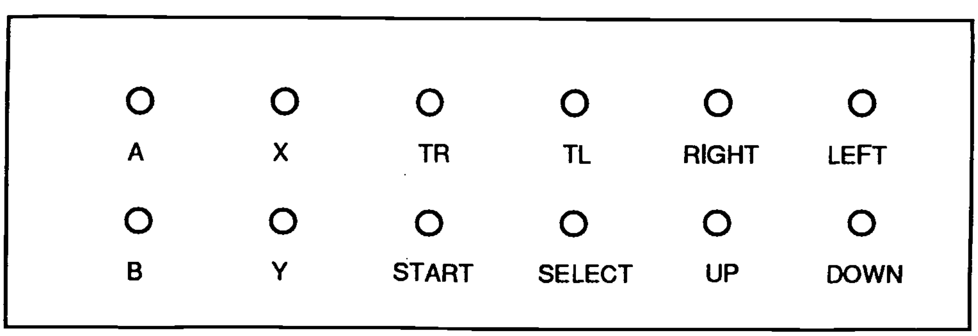

Figure 2: Switch Inputs for Super Nintendo Interface Box

MOUSE BREAKOUT: RELOCATION OF MOUSE SWITCH FUNCTIONS

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ABSTRACT

The use of a mouse is required for computer drafting programs, and is important for the efficient use of a computer for other tasks. The modification of a mouse for use by an individual with bi-lateral upper extremity below-elbow prostheses is described, which enabled the user to control direction of the cursor with the right prosthesis, and activate the mouse switches with the left prosthesis.

BACKGROUND

The use of a mouse for computer operation was initially limited to Apple and Apple Macintosh computer systems, but has become an important part of the operation of IBM and IBM-compatible computers with the advent of Microsoft Windows. For computer users who cannot activate the directional and switch closure functions of the mouse with one extremity, its use becomes problematic.

A referral was made regarding the adaptation of a computer workstation for an individual who used bi-lateral upper extremity, cable-driven, below-elbow prostheses. The client was enrolled in a Computer-Aided Design and Drafting (CADD) Program at a local community college, and was receiving training on the use of AutoCAD.

The client and instructor requested a worksite modification to create a system that would let the client control the direction of the cursor with his right prosthesis, and activate the switch functions with his left prosthesis.

Since the client was not at a definitive worksite yet, the instructor specified the Microsoft Serial mouse as the system that would be preferable, as he estimated that the equipment would be present in approximately 80% of the environments that the client may find employment.

OBJECTIVE

The goals of the project included the provision of a mouse system that the client could take into a worksite and merely plug into the existing computer equipment that would be present. The maximization of commercially-available components of the system was also a strong consideration.

METHOD / APPROACH

Several conceptual modifications to the mouse were considered at the onset of the project. First, the fabrication of a Y-adapter cable to enable two mice to be plugged into the computer simultaneously was investigated. If this could be achieved, the use of two mice, with one held in position and having adaptive levers positioned above the mouse switches, would create the separate locations for the mouse functions. This was found to not be possible, as the computer would detect two mice present and not react normally to the use of either.

Second, the fabrication of a Y-adapter cable with pin connections electrically separated to enable the mouse direction signals to emanate from one mouse and the mouse switch closures to emanate from the other was considered. This was also found to be unfeasible, as the pin functions of the connector are shared cannot be separated from one another.

Third, the modification of a single mouse was considered. This could be achieved through the soldering of a 6'-long cable to the contact points of each of the single mouse's two switch leads, and the attachment of a 1/8"-diameter female jack to the end of each pair of leads. This would enable the attachment of any two appropriate switches, having 1/8"-diameter male plugs or adapters. This option was the modification performed and issued to the client (Figure 1). Two plate switches from Don Johnston Developmental Equipment were incorporated into the system.

To provide the client with a surface to hold when using the mouse for directional control of the cursor, an L-shaped fin was fabricated using 1/8"-thick Kydex, and attached to the top of the mouse using Scotchmate fastening material (Figure 2).

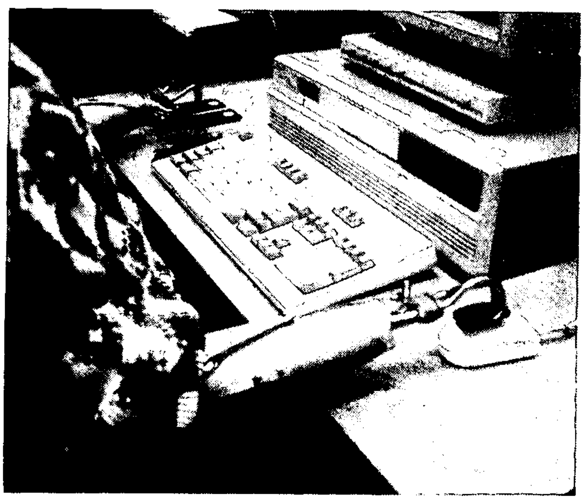

Figure 2

RESULTS

With the adapted mouse installed at the computer workstation, the client was able to control the direction of the cursor with the mouse's vertical fin and the switch functions with the relocated switches. The client did not want any rigid positioning or different orientation of the plate switches, other than merely placing them on the table. The client felt that he did not have any difficulty in locating the switches, and did not have to make visual contact with them.

DISCUSSION

The separation of the direction and switch functions of a computer mouse was thought to be an issue that had been addressed many times in the past, and a convenient, commercially-available solution was sought. None could be located, however, and the modification of a mouse became necessary.

One possible change to the L-shaped fin adaptation to the computer mouse would be the connecting of the two plastic surfaces with a hinge or piece of self-adhesive velcro. This would provide a somewhat flexible connection, and help avoid any occurrences of the mouse lifting off of the table surface.

SOURCES

Microsoft Mouse - Serial Version
Contact local computer supply stores.

Plate Switches
Don Johnston Developmental Equipment, Inc.
1000 North Rand Road - Building 115
Wauconda, IL 60084 USA
(708) 526-2682

Kydex
Check with local plastics suppliers.

Scotchmate Fastening Material
Check with local 3M distributors.

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FUNCTIONAL EVALUATION OF THE DATAHAND® KEY ENTRY SYSTEM USER EXPERIENCE EVALUATED BY QUESTIONNAIRE

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ABSTRACT

Repetitive stress injury incidents are rising in the work place. Extensive use of flat keyboards for data entry is attributed to this rise. DATAHAND®, an innovative approach to keyed data entry, provides the operator comfortable hand and finger motion while performing tasks requiring the use of keyboards.

This paper presents the results of a questionnaire survey for the evaluation of the first twenty five users of the DATAHAND® device for keyed data entry. Responses by users in questionnaire studies suggest that this alternative entry device offers a reduction of symptoms for users with hand pathology.

INTRODUCTION

Recent years have seen a substantial increase in the number of computers and the proportion who use them heavily [4,6]. Intensive use of keyboards result in high levels of discomfort [7] and is clearly a major factor in the incidence of cumulative musculoskeletal disorders among office workers. Repetitive stress injury in the United States has been characterized as an epidemic. From 1989 to 1990 the rate increased 23%, but among office workers it more than doubled (OSHA, Bureau of Labor Statistics).

Factors characteristic of keyboard use (repetitive motions, wrist abduction and dorsiflexion, constrained posture and constant application of static forces such as are required to support and pronate the hands) are implicated in a number of studies as contributors to the rate of musculoskeletal problems in video display terminal (VDT) work. No clear determination of factors has been ascertained but there is a strong incentive to provide alternatives to the standard keyboard to reduce or eliminate these sources of stress.

There are several alternatives to conventional keyboards either on the market today or will be soon. All these alternatives are based on the conventional flat keyboard in differing configurations that attempt to address keying stress factors by including various combinations of designs to reduce wrist angles and hand pronation, provide hand support, reduce key force and/or key motion, and distribute the workload more efficiently among the fingers. DATAHAND® radically changes the concept of keyboards (Fig. 1). The traditionally flat keyboard is replaced by two hand units which support the hands and allow for the hand to be in the "Position of Function" when performing keyed entry. DATAHAND® three dimensionally wraps the keys around the fingertips. Every key is positioned within a few millimeters of the finger surface that operates it. This new five way keying switch module makes all keys "home keys" and places the fingers several millimeters from each key cap reducing strike force and lessening the stretching motions required to reach keys not located directly below the resting finger position. DATAHAND®'s unique design allows the user flexibility to place the "keyboard" in an individually comfortable position and allows for support to forearms with use of chair armrests.

Actual users are the best source for information relating to ease of use, reduction of symptoms, and feasibility. Questionnaires utilizing an independent interview process provide an excellent method for collection of data.

Figure 1 The DataHand™ Device

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METHOD

The initial 39 people who were shipped DATAHAND® devices were contacted by telephone. Fourteen of the 39 people were not using DATAHAND® due to changes in medical status, learning incentives, or incompatibility to work environments. Each of the remaining 25 people were interviewed using a survey form (questionnaire) containing more than 80 questions relating to demographics, diagnosis, history, pain assessments, alternative device usage, learning curve time frames and, ease of use. Each interview was conducted by a single researcher and was between 15 and 30 minutes in length. The results are based on the twenty five people actually using DATAHAND® at the time of survey.

USER PROFILE RESULTS

Answers from 25 users of the DATAHAND® were tabulated. These results include responses given by users when asked about use of conventional keyboards.

Twenty five users ranging in age from 26 to 54 (average 38.2 years) were interviewed. Nine were male, 16 were female. Types of work included programming (9), secretarial (4), numerical data entry (3), writer/publisher (3), data analysis (2), medical records (1) and training (1).

Experience and history revealed that the average hours for use of a flat keyboard was 6.1 hours. Physical symptoms included hand pain, numbness, tingling, pain radiating up the arm, pins and needles, swelling, hand heaviness and, weak grip with hand pain (19), numbness (13) and, tingling (12) reported most frequently. Medical help was sought by all but one user with the majority (13) seeking help within the first six month of symptomatology. The majority (19) reported that pain and symptoms increased gradually but six reported that the onset of symptoms was very rapid.

A pain assessment scale rating pain on a scale from 1 to 10 with 1 being the least and 10 being the greatest was used to assess pain throughout the questionnaire. Using this scale, users rated pain levels while keying on a flat keyboard at 7.7. When asked to report how long the user could use the keyboard prior to pain or symptom onset the average length of time was approximately 30 minutes. Pain when keying on a flat keyboard started at a level of 3.2 (scale 1 to 10) and increased upwards as activity continued. Nineteen reported presence of symptoms at night. Twenty three reported presence of symptoms during the day. Symptoms were present during many normal daily activities such as driving (23), reading (20), holding children (11), telephoning and, performing household chores.

All but one user was diagnosed by a medical professional. Medical specialties for the professionals included hand surgery, orthopaedics, general practice, neurology and, homeopathy with the majority of diagnosticians being hand surgeons (9) and orthopaedic surgeons (6). Users reported numerous physical tests performed to aid diagnosis. These included nerve conduction (16), x-rays (14), electromyogram (14), Tinel's (2), Phalen's (2) and MRI (1). The most common diagnosis was carpal tunnel syndrome (10) and tendinitis (5). Other diagnosis included tenosynovitis, synovitis, and nerve compression. Most users (17) have discussed hand surgery with their physician but only seven have actually had surgery. Medications for pain management included nonsteroidal antiinflammatories, antiinflammatories, and steroids. No clear result is available to indicate the success or failure of these therapies. Most users (20) are currently medication free.

Other methods to relieve pain and symptoms included special equipment (76%), rest (72%) and exercise (25%). The most commonly used special equipment included splints. Most users reported that none of these methods greatly reduced symptoms.

DATAHAND® PERFORMANCE RESULTS

Twenty two users reported the primary reason for switching to DATAHAND® to be the result of a medical condition. Sixteen (64%) reported that the impact of their medical condition on their job performance resulted in risk of career loss while seven (28%) reported the impact to reduce productivity. When asked to rate the level of concern for job/career loss on a scale of one to ten (ten the highest) the users reported an average of 7.1 for concern.

Pain assessment, using the pain scale of 1 to 10 with 10 being the highest, when keying on a standard flat keyboard is reported at a level of 7.7 but was somewhat reduced (6.1) just prior to use of the DATAHAND® device. This may be attributed to change of work habits or use of special equipment such as splints, wrist rests, and voice recognition systems. However, pain assessment scores upon first use of DATAHAND® drop to 4.3 (44% and 29% change respectively) and further drop to 2.2 (48% change) when asked to assess pain now.

Average months of DATAHAND® use is 3.3 with daily hours averaging of 4.4 hours. Sixteen (64%) reported reduction of symptoms while six (24%) stated that the symptoms had not changed and one reported increased symptomatology. First recognition of reduction of symptoms occurred in an average of 7.4 days from first use of DATAHAND®. Of the seven reporting swelling as a symptom, five reported that the swelling had gradually reduced with the use of DATAHAND®.

Other questions related to learning curves and productivity when using the DATAHAND® device. Data is inconclusive due to length of usage time. DATAHAND®'s design places all but four keys in the standard QWERTY positions, but incentive to learn something new and the retraining of muscle memories is necessary for most touch typists. Most users (22) reported reaching comfort in use after 2.6 weeks, but also reported that while keying speed did not appear to equal flat keyboard speed it would only be a matter of time before it did equal or exceed it. Three users reported that their word per minute speed is greater on DATAHAND® than on the flat keyboard. Fourteen users have chosen to use DATAHAND® exclusively, while eleven task share with flat keyboards. The most common reason for task sharing is use of multiple computers.

SUMMARY

This preliminary study indicates that DATAHAND® is potentially a viable alternative to traditional keyboard devices. The initial pain reduction demonstrated is impressive. This questionnaire is the first step - it establishes a baseline. DATAHAND® warrants more extensive and longer term review. DATAHAND®'s unique design may also provide help for other categories of users with problems such as arthritis, spinal injury, or blindness.

Repetitive stress injury incidents continue to be a significant problem for people who make intensive use of keyboards. Studies including objective measurements such as strength evaluations, surface electromyography to identify muscle dysfunction, postural asymmetry, and functional outcomes, and vibrometry are in progress. Periodic evaluations to assess long term use are needed. For people with hand pathology such as Carpal Tunnel Syndrome and tendinitis, the DATAHAND® design offers much needed support and may provide the opportunity for continued job security.

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TOWARDS GESTURE RECOGNITION FOR THE PHYSICALLY IMPAIRED

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ABSTRACT

This paper describes a study into the automatic recognition of gestures made by physically impaired people. A large data set of arm gestures were collected from 9 disabled people using a Polhemus 3 Space Isotrak. The classification performance of three pattern recognition methods were investigated. The best classification result achieved was 76.8%. Further work is necessary on defining more robust features to represent gestures in order to improve the classification rate.

INTRODUCTION

Most interaction with computer systems today takes place using a keyboard and mouse for input and a screen for the output of information. However these modes of interaction (keyboard, mouse, screen) do not make full use of the human sensory and motor potential. Most people have five senses: sight, touch, hearing, taste and smell, and a rich and complex motor ability, which include the abilities to gesture, speak and look. They are largely under-used when we sit down to work with a computer: "the vast majority of us peck at arrays of buttons (called keyboards) and push little boxes (called mice) around on pads"(1).

There is an information bottleneck at the interface in that the full communication bandwidth (information transfer rate) available to people is not being utilised. When we communicate with other people we use multiple modes of communication such as speech, hand gestures, eye-gaze and touch(2). These rich and expressive modes of input are generally not available to the majority of users when communicating with a computer. Hence information transfer is limited and unnatural.

The problem is exacerbated for those with disabilities. For example, many people with physical impairments have great difficulty or find it impossible to type, or to control a mouse. Therefore their access to computer systems is restricted. Alternative input modes, using devices such as single switches, suck-blow tubes and joy-sticks, typically have to be designed for this group to allow them to use a computer. Communication using these devices is even more stilted, resulting in a much lower bandwidth than is possible with keyboard and mouse.

As Shein points out, interface technology (for disabled people) is in a rut(3). Today's interface technology still cannot support real-time interaction, and for example non-speaking people with severe physical impairments remain at a tremendous disadvantage in communication. Shein believes that by widening the information bandwidth between user and computer system, the quantity of information transferred can be dramatically increased, thereby increasing the communication rate. This wider bandwidth of information can be captured by increasing the number of input channels to include gesture, voice and other aspects of body language.

We are developing a system which allows software developers to easily add alternative input channels to their applications. As part of this development, we have been investigating gestural input for physically impaired people as an alternative input channel.

GESTURAL INPUT FOR PHYSICALLY IMPAIRED USERS

Many physically impaired user of computer systems lack the fine motor control necessary to use a keyboard and mouse. Alternative input devices have to be used. A wide variety of such devices have been devised, but a commonly used one is some form of switch input (either single or arranged in a small array). However severely physically impaired people have difficulty in using even a large and carefully placed switch. The disabled person may also not have enough force to depress the switch and/or the act of targeting on the switch can cause muscular spasms. It can be very difficult to determine optimum switch types and positions for someone with a severe physical impairment, and, with degenerative diseases, the type and position of the switch may have to be changed on a number of occasions as the disease progresses.

These limitations could be overcome with a gestural interaction technique. If a computer system could reliably recognise gestures made by an impaired individual, then these gestures could be used to control applications in the same way as switches do and some of the disadvantages of switches may be overcome. The user should not be forced to make a particular type of gesture (i.e. targeting on a switch at a particular location), but would be free to make any gesture they chose. Such gestures potentially could be made anywhere in a "gesture space" around the user (depending on the gesture tracking technology employed), whereas switches, once located, are at a fixed point in this space. No force is required with gesture input. In addition gesture recognition could also potentially adapt automatically over time to changing movement patterns of the user. This is analogous to changing switch types and/or locations to cope with degenerative diseases. Finally a user may have a larger repertoire of movements, if they are free to make any ones they wish. This could lead to a significant increase in bandwidth between user and computer.

A number of researchers are investigating gestural interaction methods as an alternative access method for physically impaired individuals(4,5,6,7,8). There have also been a number of studies carried out into gestural interaction for non-impaired individuals. However currently there are no standard method or recommended methods for gesture recognition. Recognising and representing human gestures is a challenge that rivals speech and handwriting recognition in its potential difficulty(9).

Two particular recognition techniques have been used with some success over a large number of years in both speech and handwriting recognition research. These are robust and mature pattern recognition methodologies. The aim of this study was to investigate them further for the recognition of gestures made by physically disabled people.

Data Gathering

A total of 1098 gestures were collected from 9 disabled people. 5 were CP and 4 were Spastic Quadriplegia. Gestures were collected on a number of different data collection sessions using a Polhemus 3 Space Isotrak. (The Isotrak is a position monitoring device that provides the six degrees of freedom (x, y, z, yaw, pitch and roll) of a small lightweight sensor with respect to a fixed source). The sensor was attached to the left or right wrist of the subjects, the data thus represented wrist/arm movements only. Data was captured at a 40 Hz sampling rate. Each subject was asked to provide examples of gestures they found easy and natural to make. No definition of the form the gesture should comprise was given and no meaning was attached to each gesture. The intention was not to dictate gestures, but rather to allow each subject to make movements that were simple to perform and repeatable. One subject supplied 5 different classes of gesture; three subjects supplied 3 different classes and two different classes were supplied by the remainder.

The gesture data was segmented into discrete gestures using a semi-automatic procedure, involving some manual input.

Feature Extraction

A very important component of any pattern recognition system is the feature extraction process, where the raw input data is pre-processed to extract features to represent the data. These features are chosen to maximise the important differences between patterns of different classes. Feature extraction is more an art than a science, and typically much experimentation is required with different feature sets to determine the optimum one. In this study a total of 15 different feature sets were explored, including those containing velocity, acceleration and frequency domain parameters. It was found that converting the raw displacement data to relative displacement data, so that each movement vector in a gesture was made relative to the starting position, gave the best recognition performance.

Pattern Recognition Algorithms

Three different pattern recognition algorithms were investigated using the relative displacement feature set as input, namely: linear classification (LC), dynamic programming (DP), and hidden Markov models (HMM's)(10). LC is a simple template matching method where an unknown candidate gesture is matched against known reference gestures representing each class to be recognised. The candidate is assigned to the reference class that returns the lowest score in the matching process. DP and HMM's are techniques used extensively in automatic speech recognition and cursive script recognition. DP is similar to LC except that it takes account of different lengths of candidate and reference patterns by 'warping' the registration path between the candidate and reference templates. With HMM's a model is built to represent each gesture class (by using a training set of reference gestures), and the unknown candidate classified against each model. The candidate is assigned to the model class that returns the highest score. As with DP, HMM's can be used to account for gestures of the same class having different lengths.

Table 1 shows the classification results for the three classifiers, averaged across all 9 subjects. The first gesture of each class was used to train the HMM's and as the reference gestures for DP and LC. This is analogous to the user training the system once before use with one example of each type of gesture to be recognised.

Table 1 shows that both DP and HMM give an improvement in classification rate over the simpler method of LC. However the classification rate is not good with either method.

Therefore a number of different training strategies were investigated in an attempt to improve the classification rate.

Method	Class. (%)
LC	54.2
DP	74
HMM	67

Table 1

These were: (a) training the system each time it used by using the first gesture of each class from each data collection session to train the models or as reference templates; and (b) using the candidate gestures to modify each reference models/templates during recognition. That is allowing the model or reference templates to adapt over time to more closely match the changing patterns in the candidate gestures. The latter strategy had two different conditions: (i) adaptation was only done if the gesture was correctly recognised (supervised learning) and (ii) adaptation was done whenever a gesture was recognised, i.e. even if it was recognised incorrectly (un-supervised learning). Table 2 shows the classification rate obtained for each of these strategies.

Method	Class. (%)
DP: Train Per Session	76.8
DP: Supervised Learning	76.1
DP: Un-supervised Learning	74
HMM: Train Per Session	70.2
HMM: Supervised Learning	60.9
HMM: Un-supervised Learning	67.6

Table 2

The results show that training the recognition system each time it is used results in only a small improvement in classification rate for this data set. Different learning strategies also did not provide a dramatic increase in performance and in one instance the classification rate reduced

CONCLUSION

In these experiments DP performed better than HMM as a classification method. However the classification rates obtained with both the DP and HMM methods, using a variety of training strategies, were not adequate for a practical gesture recognition system. It is probable that the features used were not powerful enough to adequately represent the differences in the gesture classes. We intend to investigate further ways in which to represent gestures made by physically impaired people. It is interesting to compare the classification rates obtained with disabled users with those obtained for a comparable data set collected from able bodied users. In the latter case a best classification rate of 98.6% was achieved, which implies that a practical recognition system is viable for this group, using the same feature set and recognition algorithms. Gesture recognition for disabled people however is a more difficult problem requiring more powerful techniques but such techniques could lead to more robust recognition performance for all classes of user.

ACKNOWLEDGEMENTS

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HAND CONFIGURATION PRE-PROCESSING TOOL FOR SIGN LANGUAGE RECOGNITION

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ABSTRACT
This paper presents a view of our Sign Language (SL) recognition system, ARGO, based on linguistic knowledge of SL. In order to improve gesture recognition algorithms, we have choose to separately treat each hand gesture parameter (configuration, orientation, location and movement). In a first step, before designing the recognition algorithms, a pre-processing tool has to be designed, for each parameter. Indeed, the transducer inaccuracy require to remove incorrect measures and to add correct ones. At the moment, the transducers used to capture gestures are cameras or data gloves.
We detail more precisely a pre-processing tool for the hand configuration parameter. It is based on anthropomorphic knowledge of the human hand (upon bones and joints).
Cinematic knowledge allows us to filter the data provided by gesture transducers, by erasing the incorrect data, and to reconstruct the hand configuration, even when all the respective position values of its different components are not known, by the means of rotation and translation matrix product.
Moreover, such a model provides a representation of the hand which is independent of the transducers used to capture signs. It can be used both with camera or glove based system.

KEYWORDS
Sign language recognition, Anthropomorphic model, Filtering, Reconstruction

BACKGROUND
Sign Languages provide an effective and efficient means of communication between members of deaf and non-vocal communities. However the majority of hearing persons are unfamiliar with such gestural languages. The ideal communication system between the two communities would be capable of converting Signs into vocal and vocal into Signs.
Such kinds of translators need to manipulate dynamic information from hands, facial mimics, gaze and other parts of the body. New transducers are developed for tracking hand gestures, such as the data gloves (DataGlove© from VPL, CyberGlove© from Virtual Technologies...) associated with 3D movement captors (3space® Isotrack® from Polhemus...). But there are also some studies on human movement video sequences.
New kinds of algorithms are developed with the goal of recognising hand gestures. These algorithms are based on classical pattern recognition methods. Most of them use neural network methods [1], [2], [3]; others use dynamic programming [4], or others techniques [5], [6]. Gloves give easier mean of real-time capture of the hand movement. Only the study [6] is based on video sequences.
These studies do not take into account the origin of the signal to be recognised: The hand. It stands to reason that some information of the cinematic and dynamic possibilities of the hand (and other parts of the body) would help gesture recognition.
In robotics domain or in graphical animation domain [7] [8], realistic gestures are produced by the means of an anthropomorphic model of the part of the body to be represented.
In this study, we propose to use such an anthropomorphic representation of the hand for a part of the recognition process.

SIGN LANGUAGES
Sign Language is a complete language, with its own vocabulary and syntax, It is not an international language, as each country developed its own vocabulary. But foreigner deaf people communicate far better together than hearers who speak different languages. This is due to SL iconicity and common structure in Sign construction and in sentence construction [9].
A Sign includes several parameters, realised simultaneously. We can precisely describe a hand gesture with four parameters [9]. Each parameter provides a different kind of syntactic or semantic information

- The hand configuration (i.e. the shape of the hand): instrumental information.
- The orientation of the palm: voice (agent, patient) information.
- The localisation of the hand: corporal locative information.
- The hand movement: verb aspects information.

Each information is provided simultaneously and independently.
Different studies done in our laboratory with a DataGlove have shown that a global data treatment give greater importance to the configuration parameter in the recognition process of dynamic gestures [3], [5]. The use of several recognition algorithms working in parallel will allow us to design dedicated tools, one for each parameter, given to them an equally importance. Our general system of Sign

recognition, ARGO, is based on such a linguistic approach (see figure 1).
Before working on the recognition aspects of the system, we have to take into account the capture problems due to the transducer inaccuracy. For example, the DataGlove optic fibres provide inaccurate, sometimes incorrect, values of joint angles; with the cameras, there is temporary lack of some hand parts, which are hide. So we have initially designed a tool dedicated to the configuration parameter. It is based on static anthropomorphic knowledge on the hand, containing information like minimum and maximum joint angles, size of the bones, degrees of freedom, and so on.

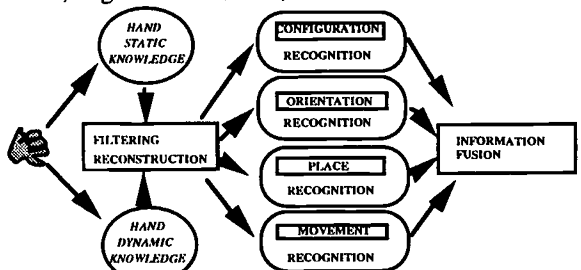

Figure 1: Capture and recognition parts of our Sign Language recognition system ARGO.

OBJECTIVE

To be useful, the hand model must own the following features

- Independent of the transducers.
- Ability to reconstruct the hand when any value of any part of the hand has changed.
- Ability to be used both for hand gesture recognition and hand gesture generation.

The design of an anthropomorphic model allows us to obtain independence towards the transducers. We can use gloves, cameras, or the two systems, the last one complementing information given by the first one.
We represent the complete hand close as in the real life (but with some simplifications) [10], and instanciate the values available by the mean of the transducers. For example, a DataGlove allows to instanciate some angle values relating to the joints of the fingers; with two cameras, we can detect the position of the tip of the fingers in a 3D space.
If enough information is given by the different transducers, the relative position of the different elements allows us to reconstruct the whole hand. This reconstruction allows us to send complete information to the recognition algorithms and to correctly display the hand on the computer screen.
Moreover, the cinematic possibilities of the different elements of the hand allows us to filter the data and keep only the valid values. This kind of filter, based on anthropomorphic knowledge, can send proper gestures both to a recognition system and an animation system.

HAND MODEL

Basic structures

The two basic structures composing a cinematic model are the joint and the bone.
The joint. Each kind of joint owns a name, two links with a bone, and initial position in regard with the position of a given referential (see the position of the thumb in figures 1 and 2). Moreover, we can differentiate three kinds of joints, depending on the DOF number (1, 2 or 3). Each DOF owns minimum, maximum and courant values.
The bone. Each kind of bone owns the following features: a name, a height, a position and an orientation (relative to the adjacent bones). This last feature can be represented by a 3D vector (see figure 3). In the case of the hand, we can specify three kinds of bones, depending on the joint number they are linked with (1, 2 or 6 for the carpal bones - The set of carpal bones is considered, simply, as one single bone linked with the five fingers and the arm). Moreover, we can specify the links between the bones and the joints: For example, a distal phalanx is always linked with a one-DOF joint, a middle phalanx is always linked with two one-DOF joints, etc.

Higher-level structures

It can be useful to be able to manipulate intermediate structures for specific processing. For example, in a hand model, we can define the finger structures. According to the anatomic knowledge, we have to differentiate two kind of fingers: The thumb and the finger (see figure 2).
Figure 1 illustrate the different bones used in these structures. The DOF are represented by the grey arrows.

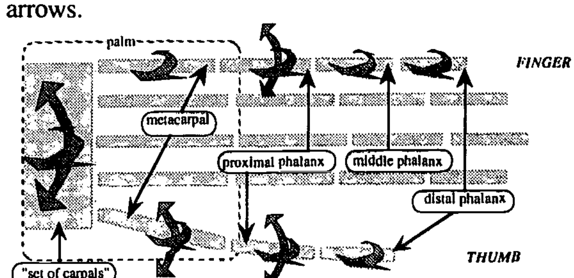

Figure 2: Cinematic knowledge on the hand

MODEL CAPABILITIES

Filtering

The anthropomorphic representation gives cinematic information on the hand that allow us to remove errors due to transducer inaccuracy or to noise in the signal. Two kinds of filters have been considered:

- A *static filter*. If an incorrect value is detected at a given time, the value is removed. For example, if a angle value of more than 90° is given for a meta-carpo-phalangeal joint (between a metacarpal and a proximal phalanx), this value is not kept. The correct value will be computed during the reconstruction or by the dynamic filter.
- A *dynamic filter*. This filter operates on a set of static instances, representing a part of the gesture.

When values are unknown, an interpolation is done, based on previous and successive values, if they are known. For the moment, the interpolation use some knowledge of hand cinematic, but in the next step of this work, it will take account of its dynamic, such as the maximum speed of a finger flexion, the dependence between the fingers, etc.

Reconstruction

The information given by the transducers can be of several kinds: The gloves can give angle values, the camera can give position, height and orientation values and the 3D magnetic captors can give position and orientation values (we can imagine that future systems will add tactile information, by the means of tactile captors). One of the aims of the hand model is to provide a reconstruction tool, capable of using all kinds of measures to reconstruct the whole hand at any given time.

By using classical translation and rotation computations in a 3D space, one can reconstruct the joint angles of the hand if the positions of the bones are known, or the position of a bone if the joint angle is known.

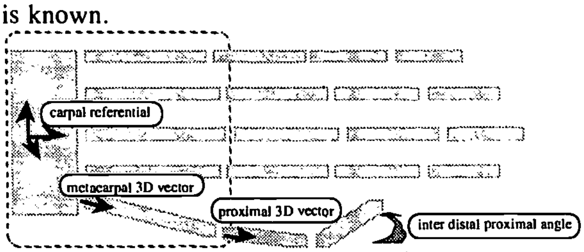

Figure 3: Reconstruction of the distal phalanx vector

The figure 2 shows an example of the thumb distal phalanx reconstruction. A new inter distal proximal angle value is given by the means of a DataGlove optic fibre. The new distal phalanx vector is computed by the means of a rotation matrix. This new vector allows us to display the new position of the distal phalanx.

The different parts of the hand are reconstructed only if new values are not known. Otherwise, the computing reconstruction is propagated in any direction, along the bones.

The use of several transducers requires the fusion of the different information. This is done in a module which synchronises the different samplings, and then, the synchronised information are sent to the model.

IMPLEMENTATION

In order to maintain the coherence of the model specification and the computer implementation, we have chosen to use a object programming implementation. In addition, a great speed is required in the computing of the reconstruction and the screen representation. This has led us to implement our model in C++ on a Silicon Graphics station.

We are currently collecting a large corpus of gestures, which will allow us to realistically measure the benefits obtained by using this model. We will be comparing our results with earlier work based on neural networks [3].

CONCLUSION

In this study, we have proposed an anthropomorphic model of the human hand, in order to improve current recognition algorithms. This model allows us to represent the hand without a priori knowledge of the transducers used to track the hand gesture. The model can be used both for gesture recognition and gesture production.

The next step will include an arm representation, which will provide information on the arm position and orientation. Moreover, more dynamic information on the human hand and arm will be integrated in the model. These information will allow us to realise the same kind of tools for the others parameters: The orientation, the location and the movement.

A third step will include the design of dedicated recognition algorithms for each of the Sign parameters.

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DEFIE: AN INTELLIGENT AND FLEXIBLE INTEGRATED ENVIRONMENT FOR DISABLED AND ELDERLY PEOPLE

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ABSTRACT

The goal of DEFIE project is to develop a generic model and an intelligent integrated system that, by exploiting current multimedia and future technologies, will allow a friendly and safety-critical user interaction with smart home and applications. Different alternatives of I/O and control devices can be integrated to allow the use of the same system to a larger group of users including different categories of disabled, elderly people and persons with degenerative diseases. Particularly important is the role played by intelligent device drivers and by the redundancy of user interfaces. New interface styles based on properly combined devices (i.e. "virtual sense" approach[1]) will permit to increase user perception and interaction capabilities. Among the several functionality provided by the system, it is worth to mention telemaintenance and remote system monitoring facilities to allow software update, remote user support and remote environment monitoring.. DEFIE is a research project partially funded by ECC in the R&D frame programme TIDE, grant number P1221.

BACKGROUND

Mouse, keyboard, monitor represent fundamental channels of direct communications between users and computer, nevertheless people with disabilities and degenerative diseases find these conventional I/O impossible to use, extremely difficult from a manipulative point of view, too primitive to support their needs and increase their productivity in home and workplace environment. Generally, four basic factors prevent the realisation of successful solutions and products:

- immaturity of computer and I/O devices technologies,
- to consider disabled, elderly and people with degenerative diseases as a ghetto completely isolated from the social and economic life and not capable to be productive,
- only survival problems are tackled
- the potential market was considered too small, difficult and not interesting from economic and commercial point of view.

Advances in computer technology (e.g. multimedia, new special devices), cost decrease and progress in computer programming and telecommunications have created the basis for the development of new methods for providing computer access and significant solutions. DEFIE belongs to a new generation of Rehabilitation Technology and products based on the concept that the same system and services can be exploited, with light and cheap modifications, by common users as by disabled and elderly people with concrete benefits in the daily life and gain in productivity.

STATEMENT OF THE PROBLEM

Existing solutions that increase an independent living are currently available on the market, nevertheless all these systems provide limited and poor solutions that can solve only a limited subset of user needs - multitude of isolated solutions. On the contrary, the research carried out in DEFIE intends to extend and integrate, within a common framework (i.e. model), existing technology, components, interfaces, control devices, single-solution packages, services and new developments. The realisation of a correct computer based Rehabilitation Technology is based on two key aspects: (i) guarantee an effective use of the system and a concrete support during the every day life and work activities through an appropriate number and type of functionality with acceptable performances, (ii) integrate and provide a multitude of alternative input/output facilities, including speech recognition system and vocal synthesiser, without any impact on the system architecture. To accomplish a satisfactory level of quality, a system should provide a wide range of integrated capabilities:

- Access to basic telecommunications services, typically telephone, fax, modem and electronic mail facilities. A complete and simple access to these services is not only essential during the every day life but allows to accomplish basic work activities and can guarantee a considerable comfort to elderly people with a reduced mobility or living in rural areas.

- Access to external services provided by the community such as: bank telelink (e.g. simple and complex financial transactions, payments, information on bank account, etc.), newspaper telelink, television teletext, access to remote data bases, teleassistance and alarm services, teleshopping, minitel, etc.. Information

[1] Integration of different I/O devices to increase user perception capabilities and provide valid alternatives to poor user-machine interactions

distribution services shall be considered, especially today, beneficial for a quick and complete social and economic integration.

- Environment control facilities represent another central and important step in the direction of a high quality independent living. For elderly and people with diseases their general comfort (e.g. metabolic rate) can strongly influence their capacity to positively react to physical impairments and solve additional psychological problems. An efficient autonomous control and monitoring of environment, including alert management, can partially or completely eliminate specific assistance provided by relatives or external personnel with an important reduction of social costs.

- Manipulation and archiving of different type of data are additional basic capabilities that can allow simple operation such as: letter or document writing/reading (extremely important for blind and people with visually impairments), to make calculations and exploit spreadsheet potentialities, to archive and retrieve information, to handle an agenda/organiser or telephone directory and notepad.

RATIONAL

DEFIE project intends to produce a totally integrated multimedia system based on various types of I/O devices and facilities, including speech recognition system and vocal synthesiser. Several basic elements characterise the technical DEFIE achievements:

- Modularity and integrability of various functions, with the possibility to inter-connect and chain together basic functionality implemented in different DEFIE subsystems.
- Total independence of I/O functions from applicative functions and consequently autonomy of the system from the selected I/O and control devices.
- Optimisation of human computer interfaces with respect to specific input/output devices selected to execute, gradually, more complex operations, especially in working environment, in a shorter time and without errors.
- Independent living and socio-economic integration through the availability of several integrated facilities dealing with telecommunications, information handling, access to external services and environment control.

DESIGN

DEFIE is a system that groups and integrates several hardware and software subsystems performing well determined functionalities. A common system component - the Core System- exports the basic DEFIE services and masks I/O and control devices to the upper modules. This modus operandi adopts an approach similar to the OSI layered model that logically separates DEFIE in several functional layers, encapsulating specific policies and mechanisms, to export well defined functions to the upper layers (see figure 1.a).

A strict object-oriented approach is applied to decompose the system and encourage a correct design of each DEFIE layer. The above layers can be gathered in three logical groups according to their specific characteristic and functionality:

i. System Software and Hardware (layers 5,4)
The computer hardware, I/O and control devices, device drivers, internal DEFIE mechanisms are hidden to upper services and applications. This part encapsulates security controls and safety critical mechanisms to avoid uncontrolled system behaviours and reduce error or fault consequences. The access to system services is made available through a set of Core primitives (DEFIE Core API).

DEFIE GENERIC MODEL

LAYER 5
Human Computer Redundant Interface
LAYER 4
Application Services
LAYER 3
Basic Services
LAYER 2
DEFIE Engine
LAYER 1
DEFIE Kernel
LAYER 0
Hardware

Figure 1.a

ii. Service Software (layer 3)
This layer implements basic services that are directly accessible to the user or available to DEFIE applications. Basic environment control services, telecom services, data manipulation and archiving functions are essentially implemented at this level (DEFIE Service API).

iii. Application Software (layers 2, 1, 0)
Human-computer interaction styles, environment control, applications and additional facilities such as telemaintenance and remote data access are gathered in this part of the architecture (DEFIE Application API).

This generic model allows the implementation of new services and new alternative I/O devices without any change in the DEFIE model. In addition, services previously implemented, can be exploited and integrated by new applications.

The DEFIE model is completely independent with respect to new hardware solutions and facilitate the standardisation process of services and I/O alternatives. The architecture, based on the previous model and depicted in figure 1.b, gives a first idea of the components that are implemented during development phase (excluding OS and basic drivers, standard protocols and other software components available in the PC basic configuration). The implementation of DEFIE system stresses portability, confining in a well defined and small number of components hardware-dependencies and system idiosyncrasy. This software modularity simplifies both the integration of heterogeneous multivendor systems and system tailoring and configuration activities.

DEFIE SYSTEM ARCHITECTURE

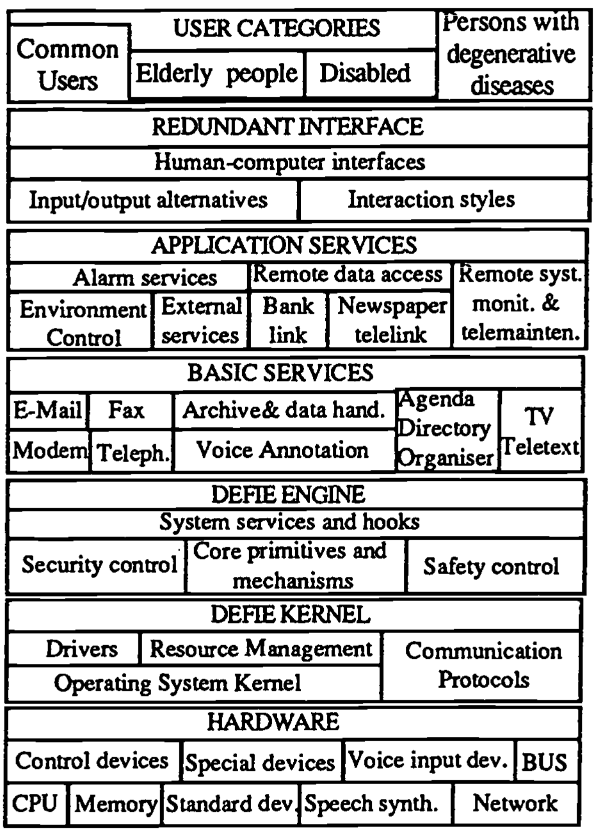

Figure 1.b

DEVELOPMENT

The context of this development is centred on a few but essential elements. The first element takes care of a better understanding of user needs and market requirements for the correct development of: a generic model, the DEFIE system architecture and the definition of APIs (Application Program Interface) to manufacturers and third party developers (i.e. set of proposed standards hooks). Secondly, based on a multi-disciplinary approach, the system is implemented taking into account neglected aspects such as: dependability, safety, privacy, openness, remote maintenance and system monitoring, usability & productivity, self training, automatic statistic data collection on user interaction. The third element concerns the verification and subsequently validation of the system impact on different categories of users previously identified. Following the statistic data, collected by specialists on the population sample of different European countries, possible weak points and inconsistencies of the system can be recovered. Final element of our development programme includes the gathering of recommendations into a forms suitable to be examined by relevant standardisation bodies. To meet the needs of different user categories, appropriate system configuration will be carried out through the selection of a well defined set of services corresponding to a clear stack selection (see DEFIE architecture). The implementation of the first prototype is carried out on Macintosh platforms and exploits Hypermedia technologies and object-oriented languages (C++).

EVALUATION AND DISCUSSION

As mentioned in the previous sections, DEFIE is a new generation of open system that intends to give support to four major user categories: disabled and impaired people, elderly people, people with degenerative diseases, common users that need computer interaction based on extremely simple and effective methods. The first releases of DEFIE system is applied to a wide range of physical disabilities excluding people with mental, behaviour and cognitive understanding problems. In particular our work is concentrated on: blind and visual impaired people; persons with orthopaedic disabilities and mobility impairments (e.g. upper or lower limbs; tetraplegic disabilities (i.e. upper and lower limbs), degenerative diseases such as multiple sclerosis, muscular dystrophy, people with multiple impairments (e.g. visual and mobility impairments). These groups cover about the 70% of disabled and impaired people in Europe. DEFIE System experimentation are conducted on different countries to better understand and evaluate different types of approaches and different solutions to: user dialogues, multilingual support and training. In particular, due to the importance of psychological factors, DEFIE provides an adequate support for short time self training modules.

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Cognitive Orthotic Shell

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Abstract

COS is a computerized cognitive orthosis shell that assists therapists and other caregivers in creating customized task guidance systems for guiding cognitively impaired clients through activities of work or daily living. COS is implemented in TURBO PROLOG® and runs on any IBM® compatible personal computer. The system was evaluated by a head-injured client and his family in their home. Task completion, accuracy, and cuing data were collected with the help of audio and video tapes, and the performance record file generated by COS. Performance using COS was compared to baseline (prior to introducing COS). Data was collected as the client was assisted by COS in his shaving task for 12 days in a two week period. COS decreased the client's dependence on the caregiver by assuming totally the cuing role from the caregiver. COS was easy to use by the caregiver, and was seen as an acceptable intervention by the client and his family.

Introduction

Brain injury often results in a host of residual impairments, both mental and physical. Brain injury could affect any of the following cognitive skills: the ability to discriminate two or more stimuli, the ability to meaningfully organize information presented to or received, the ability to generate appropriate responses, and the ability to solve problems in logical steps (1, 2). The use of computers to assist an individual in the completion of functional activities is one of several compensatory intervention techniques that have been used in the rehabilitation of persons with cognitive deficits. However, only a few systems have been developed specifically as a cognitive orthosis for brain injured persons (3, 4, 5, 6).

The cognitive orthosis shell (COS) presented here allows the careprovider to create customized task guidance systems which will decrease the client's dependence on attendants. Each task will be guided by a set of instructions presented on the computer screen and through speech output. The instructions for each task are entered by the care-provider through a set of menus during system setup. To be able to use the system, the client will need to possess sufficient cognitive skills to understand either visual or auditory cues and be able to respond through a switch. The client will respond after carrying out the instructions by pressing a single-acting switch.

Design of the System Interface

The system has two levels of interfaces, one with the client who uses COS for task guidance, and the other with the attendant or the careprovider who enters instructions and manages the system.

Interface with the Client

The client interface presents the task instructions on the computer screen and as voice output and accepts the response of the client through some input device. Components of the interface are:

1) Text may be presented in various sizes and colors.
2) Instructions are presented as voice commands through a speech synthesizer (Votrax International Incorporated®). Votrax was chosen for speech output because it has an acceptable speech quality, is relatively inexpensive, and is easily interfaced.
3) A single switch input is used for the client to respond. The client is instructed to press the switch when he or she successfully completes a task.

Interface with the Attendant

The specific cues/instructions and the time between them is customized for the client by the therapist or caregiver. This has been achieved through a set of menus which give the attendant various options such as loading the instruction set for a particular task into the database, adding, deleting, or modifying instructions in the database. The system does not require the attendant to possess any programming or other special computer skills to be able to perform these functions. The attendant uses the keyboard to input menu selections and task instructions. The different levels of menus are as follows:

1) Base menu gives an option to either choose to modify the task names or display a list of the stored tasks
2) The second menu provides the list of the stored tasks giving the user the option

to select any one of those listed.

3) The third menu is the menu for a particular task which allows the user to modify or create new instructions for a particular task and to begin the task sequence. The features which are controlled by the attendant/ caregiver are: a) wording of the cues, b) number of times the first and the second cues are presented, and c) the time needed to complete the specific subtask.

COS was written in Turbo Prolog®. It is a declarative programming language, with the ability to create menus, integrate graphics, create external databases, and control output devices.

Evaluation of the System

The system was configured for a specific brain-injured client with severe cognitive deficits but no physical disability. The client received a severe traumatic brain injury in a motor vehicle accident. His severe cognitive deficits interfered with his independence in activities of daily living and daily life management. The client's family was very supportive and provided him life skills training. The daily activity identified by the client's primary caregiver (his wife) to be the best candidate for assistance was shaving with an electric razor. A monochrome version of COS was installed on a Zenith 8086-based portable computer in the client's home. The client's family successfully learned the use of COS and were able to modify the instructions easily. The family used a data entry form to write the instructions for the system.

The information for evaluating the performance of the system has been collected from video and audio recordings of the client's baseline performance (pre-intervention) and his performance using COS. The baseline performance was taken while the client was performing the shaving task before using COS. The COS level performance of the client is his performance after COS has been customized, and the client has learned to interact with the system. COS was used twelve days over a two week period. The following parameters were measured:

1) Total time spent during the shaving task.
2) Total number of cues presented to the client by the attendant.
3) Total number of cues from COS set and the audio tapes). This is the total number of cues presented, including repetitions of the same cue.
4) Duration for which the attendant is present.
5) Number of physical interventions by the attendant.
6) Number of errors (incorrect actions or responses to a cue).
7) Time required to analyse the shaving task and enter instructions into COS.
8) Quality of the system, whether accepted or rejected by the client or caregiver.

COS along with all the database and graphics files, utilizes 370 kilobyte of disk space and contains a total of 707 unique lines of code. The system required approximately 5 to 6 man-months of initial development time followed by about 1 man-month of modification and error correction.

Results

The number of subtasks needed to perform the shaving task decreased. Both the number of cues from COS, and cues from the attendant reduced with the number of days. The duration of attendant presence while COS was being used also decreased. The attendant did not have to physically intervene during any of the days. The number of errors by the client also went down to zero. As a result of the above factors, the total time spent during shaving decreased.

TABLE 1
Pre-COS Performance of the Shaving Task

Parameters	Day 1	Day 2	Day 3	Avg.
1. Total time spent (seconds)	490	655	552	565
2. Total number of verbal cues from the attendant	9	12	10	10
3. Duration of attendant time	490	655	552	565
4. Physical interventions	None	1	None	-
5. Number of errors	2	4	2	3

TABLE 2
Performance of the Shaving Task Using COS

Parameters	Days											
	1	2	3	4	5	6	7	8	9	10	11	12
Total time spent during the shaving task (secs)	303	255	299	256	229	217	242	241	234	227	219	222
Number of Subtasks required	7	6	6	5	5	5	5	5	5	5	5	5
Total number of cues from COS	27	22	30	19	17	15	15	15	15	15	15	15
Total number of cues from the attendant	6	4	2	2	1	1	0	0	0	0	0	0
Attendant time (secs)	303	255	299	256	229	217	212	211	200	190	160	162
Number of physical interventions	0	0	0	0	0	0	0	0	0	0	0	0
Number of errors	3	2	3	2	1	0	0	0	0	0	0	0

Discussion

Pre-COS Performance

The performance of the client's shaving task before COS was introduced did not follow any set procedure or format. The shaving task was not formally broken down to subtasks. For each shaving task, the client's wife would cue the client about the various steps involved. Over 75% of the cues were in the form of questions, asking the client what he needed to do next, rather than instructing him to perform specific actions. Due to this the client would either act incorrectly or give a wrong verbal response, for about 25% to 30% of the cues. The attendant would then cue him to perform the specific action.

Performance Using COS

As the client became used to the speech output and learned to use the switch, his errors in action and response reduced to zero after the fifth day of use. As a result of this, the number of cues presented by COS reduced from 27 on Day 1 to 15 on Day 6, and remained constant after that. More importantly, the verbal cues provided by the attendant reduced from 6 on Day 1 to 0 on Day 7, and remained 0 after that. In a comparison of Table 1 and Table 2, the average number of cues from the attendant at the pre-COS level was 10, while COS provided 15 cues after the client's performance stabilized.

Even though the number of cues from COS (Table 2) are more than the cues from the attendant (Table 1), what is more significant is that the cuing function had been totally taken over by COS, leaving the attendant as an observer rather than a supervisor providing constant cuing during the task. It is also clear from Table 2 that due to the reductions in subtasks, total number of cues, and the errors, the time spent during shaving reduced progressively, averaging a little less than 4 minutes as compared to 9 minutes needed at the pre-COS level. There is a significant reduction (44%) in the time spent even on Day 1 of COS use when compared to the pre-COS level.

Conclusion

A computerized cognitive orthosis shell (COS) has been built which can be used by careproviders to develop customized task guidance systems for cognitively impaired people. The system was evaluated on a brain-injured client on a specific daily task. The system was easy to use and maintain, and did not require any programming knowledge from the attendant to enter instructions or modify them later. It decreased the client's dependence on the attendant by eliminating the need for constant supervision and cuing. A more complete discussion of COS is given in reference 7.

Acknowledgements

The authors are very grateful for the assistance and advice offered by Frank Puckett of Louisiana Tech University and Wayne Metroyer of Willis-Knighton Medical Center. Most of all, we appreciate the contributions of 'Steve' and his family.

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TO EVALUATE OR NOT TO EVALUATE? THAT IS THE QUESTION

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ABSTRACT

Evaluating usability is a necessary activity within design and development of technology used by people. It is often neglected because of potentially high costs and time demands. In the rehabilitation market, there is often insufficient resources and/or return on new products to justify expensive and sometimes lengthy evaluation. This paper describes an evaluation approach that is effective with minimal costs. As an example, a heuristic evaluation of the WiViK access software for Windows is presented.

BACKGROUND

There are three main methodologies for evaluating the usability of a system: beta testing, user testing and heuristic evaluation. With beta testing, a near complete version of a system is submitted to user sites for their comments based on unstructured use. Such testing concentrates on finding technical "bugs" rather than identifying usability problems. Since the system being evaluated is near completion, there is little opportunity to provide input into the design process.

The second and most common methodology is empirical testing in the form of user testing. Formal user testing involves representative users using prototypes in structured use to evaluate a system at many stages during the design process. Users are asked to speak their thoughts aloud. These utterances as well as the user's actions are recorded and compared.

User testing is very time-consuming and it requires a large amount of resources (money, equipment and human) and expertise to be successful. As a result, user input is often not gathered until the beta testing stage (which is far too late to have any real impact on the usability of a system).

A third more informal method is heuristic evaluation developed by Molich, & Nielsen (1990) whereby the system is examined by evaluators (who may be designers, interface experts or users). Evaluators provide an opinion about the good and bad components of the system. Their opinions are based on a set of nine heuristics that correspond to principles commonly accepted and used in the user interface community.

Training in heuristic evaluation consists of providing evaluators with the definitions and examples of how the heuristics can be applied. Evaluators then examine the systems and judge them based on these nine principles.

- Simple and natural dialogue
- Speak the user's language
- Minimise user memory load
- Be consistent
- Provide feedback
- Provide clearly marked exits
- Provide shortcuts
- Good error messages
- Prevent errors

In their findings, Molich, et al. (1990) recommend that between three and five evaluators be used to perform a heuristic evaluation because the number of problems one individual can identify is relatively low. Nielsen, & Landauer (1993) found that one individual could identify somewhere between 19 and 60% of problems (accumulated results over six different studies).

The advantages of using heuristic evaluation methodology to evaluate a system are that it is much less time consuming, requires less planning and is much cheaper than formal user testing. Thus, it can be performed at many of the design stages (from paper designs to actual prototypes), particularly the early stages. In addition, relatively few resources are required. The disadvantages of this method is that "actual" users are not necessarily involved and usually no solutions to the problems are proposed by the evaluators.

WiViK

WiViK is an software-based on-screen keyboard which replaces the standard keyboard. It provides people with physical disabilities with access to any Windows 3.1™ application. Keys are selected by pointing and clicking or dwelling.

This paper discusses the results of a heuristic evaluation that was performed on the current version of WiViK. The methodology was altered slightly in that evaluators worked in pairs instead of individually.

RESEARCH QUESTION(S)

Research questions considered for this evaluation are:

- Can we apply the methodology of heuristic evaluation in rehabilitation engineering, specifically to evaluate WiViK?
- Since heuristic evaluation can be performed by non-users, can non-users without disabilities sufficiently evaluate a system specifically designed for people with disabilities?

METHOD

Eighteen undergraduate students and one graduate student performed a heuristic evaluation of WiViK as part of a fourth year human-computer interaction course. There was one participant with a visual impairment, all other participants were non-disabled. Participation in the evaluation session was voluntary and no grades were assigned. Participants performed their evaluation of WiViK in pairs (there were 9 groups of two and one individual group).

A 60-minute training session was provided on the methodology of heuristic evaluation and a 30-minute training session was provided to introduce WiViK. The participants were then given a 70-minute period to evaluate WiViK.

Participants were provided with, but not limited to, a set of six common tasks that could be performed in WiViK in which to conduct their heuristic evaluation.

1. Perform the "Begin using WiViK" procedure from the WiViK User's Guide.
2. Become familiar with the software. Use the Help features.
3. Use the dwell and click options to try alternative typing methods.
4. Set at least four other options possible in WiViK.
5. Implement the multiple keyboard feature of WiViK.
6. Perform one other task of choice.

RESULTS

The first column in Table 1 is a summary of all of the problems categorised by each heuristic type found with WiViK listed by heuristic. There were no issues raised for the two error heuristics. The second column indicates the number of groups who reported the issue (expressed as a percent of the total number of groups).

The third column presents the design decisions made by the design team as a result of this evaluation. Issues were classified into three categories: 1) for consideration (indicated by an *f*); 2) acceptable trade-off of a design decision made a priori (indicated by a checkmark); 3) non-issue due to technical considerations (indicated by an †).

There were 27 problems collectively identified by all of the groups. However, the number of problems found by any one group was considerably less. The average number of problems identified was 6 out of 27 (22%). The largest number of problems mentioned by one group was 11 (41%).

DISCUSSION

The design team was aware of most of the problems identified in this evaluation. However, it took three years to accumulate this knowledge. The participants in this study had a minimum of training and exposure to WiViK but were still able to identify a majority of the issues with WiViK. Thus, heuristic evaluation seems to provide an acceptable and fast method for evaluating the usability of WiViK.

It is important for more than one evaluator to participate in a heuristic evaluation. In our study there were 19 evaluators working in pairs. While individual groups only found between 4 and 11 % of the problems, collectively they were able to find over 90% of the known problems with WiViK.

The number of problems identified by the groups did not seem to be greater than the percentage of problems reported by Nielsen, et al. (1990) for individual evaluators. Thus, working in pairs does not seem to provide any improvement over individuals.

Participants did not provide any solutions to the problems identified through this evaluation. However, the results of the design team review were presented to the participants several weeks after the study was completed. The discussion provided solutions to some of the major problems. For example, to solve the problem of knowing the status of the Options when selecting dwell or click mode, participants suggested using an options dialog box that would automatically appear when dwell or click was selected.

One observation made during the evaluation session and the analysis of the participant's written comments was that while the nine heuristics were useful in guiding the evaluation, there was overlap of comments among heuristics. Some problems fit into multiple categories. For example, comments regarding the lack of feedback and consistency for the dwell and click options could be classified under either "Provide Feedback" or "Be Consistent" heuristics. It is therefore recommended that evaluators provide a list of problems without necessarily classifying them by heuristic. A post-hoc analysis of the comments can find appropriate classifications.

Most of the participants in this study were non-disabled but they were still able to identify many of the problems with WiViK whose target users are people with disabilities. While this does not preclude the need for user testing, some of the usability evaluation of WiViK could be accomplished by heuristic evaluation with "expert" evaluators (disabled or non-disabled) who may not necessarily be target users. The developers of WiViK will incorporate this methodology into their design process.

The heuristic evaluation of WiViK was fast (taking only approximately two hours to set up the study and train the evaluators), and inexpensive. In addition, the methodology allowed non-users to participate in the

TO EVALUATE

Description of Issues Found	%	Design Choice
Simple and Natural Dialogue		
- Select menu heading does not describe function of submenus	10	√
- confusing sections in Help	60	*f*
- Double-Click-Shift implies something is being shifted	10	√
Speak User's Language		
- short forms such as P.Sc. and Hm difficult to understand	10	√
- confusing terminology - Send Slowly, ClipKey_Text, Send Button Down	50	*f*
- cursor key layout could be different (awkward)	10	√
Minimise User's Memory Load		
- user requires shift mode to identify shift options, loads memory	30	*f*
- screen real estate management may be a problem	10	√
- hard to remember how to restore title bar and menu bar once they are hidden	30	*f*
- procedure for using multiple keyboards confusing and complex	30	*f*
Be Consistent		
- no access to WiViK or Windows menus or objects while in dwell mode	40	√
- not obvious when in click or dwell mode (no forced selection);	50	*f*
- Hide Menu Bar and Title Bar location inconsistent with other Windows apps	20	√
- in WiViK keyboards symbols above numbers are larger whereas on physical keyboard the numbers usually larger than symbols	10	*f*
- can select more than one menu item in Select menu	10	*f*
- when change font, new font appears on keyboard but not on menus	10	√
Provide Feedback		
- Options for dwell and click modes change when select each mode and there is no feedback to user of this change	40	*f*
- Help refers to items not available in version tested	20	†
- not obvious how to repeat a key while in dwell mode	20	√
- no labels for functions keys	10	√
Provide Clearly Marked Exits		
- uses Windows exits but not clearly marked	30	√
- allows user to enter DOS full screen mode but there is no exit	20	√
- can't turn off Stickey Keys (particularly while in dwell mode)	20	√
- WiViK stops working when exiting Windows	10	√
- unsure of where "dead space" is on keyboard for break while in dwell mode	10	√
Provide Shortcuts		
- too few shortcuts	10	√
- no indication of shortcuts available	10	√

Table 1: Summary of issues identified for WiViK by heuristic

evaluation and reasonable results were achieved. Heuristic evaluation is potentially a useful evaluation tool for systems designed for people with disabilities since it is often difficult to recruit enough users for each stage of evaluation.

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THE MERCATOR PROJECT - PROVIDING ACCESS TO X WINDOWS FOR COMPUTER USERS WHO ARE BLIND

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ABSTRACT

The computer industry is currently making an irreversible shift to the use of graphical user interfaces. These interfaces present significant obstacles for computer users who are blind. At this time, there are no commercial screen readers for one of the three major graphical environments - X Windows. This paper presents current research in making X Windows accessible for users who are blind. First, standard access hooks for X Windows are discusses. These hooks support the construction of X Windows screen readers. Second, new interaction techniques for screenreaders are described. These techniques, based on earlier research in human-computer interaction, are used to create intuitive and powerful screen reading environments.

BACKGROUND

One important breakthrough in human-computer interfaces is the development of graphical user interfaces. These interfaces provide graphical representations for system objects such as disks and files, interface objects such as buttons and scrollbars, and computing concepts such as multi-tasking. Unfortunately, these graphical user interfaces, or GUIs, may disenfranchise a percentage of the computing population. A significant number of these graphical systems are still inaccessible by computer users who are blind.

There are three major graphical environments in the computing industry today: Microsoft Windows, the Apple Macintosh environment and X Windows. X is the windowing system typically found on Unix workstations. These computer systems are commonly found in many business and educational settings. Although access systems for Microsoft Windows and the Macintosh are now commercially available, a commercial screenreader for X Windows is still noticeably absent.

OBJECTIVE

Our work on this project began with a simple question, how could we provide access to X Windows applications for blind computer users. Historically, blind computer users had little trouble accessing standard ASCII terminals. The line-oriented textual output displayed on the screen is stored in the computer's framebuffer. An access program simply copies the contents of the framebuffer to a speech synthesizer, a Braille terminal or a Braille printer. Conversely, the contents of the framebuffer for a graphical interface are simple pixel values. To provide access to GUIs, it is necessary to intercept application output before it reaches the screen. This intercepted application output becomes the basis for an off-screen model of the application interface.The information in the off-screen model is then used to create alternative, accessible interfaces.

The typical scenario to providing access to a graphical interface is as follows: While an unmodified graphical application is running, an outside agent collects information about the application interface by watching objects drawn to the screen and by monitoring the application behavior. This outside agent (or screen reader) then translates the graphical interface into an auditory and/or tactile interface. Not only does the screen reader translate the graphical presentation into an nonvisual presentation, but the screen reader often provides different user input mechanisms which are more appropriate with the new interface.

APPROACH

The goal of this work, called the Mercator Project, is to provide *transparent* access to X Windows applications for computer users who are blind or severely visually-impaired. In order to achieve this goal, we needed to solve two major problems. First, in order to provide transparent access to applications, we needed to provide a framework which would allow us to monitor, model and translate graphical interfaces of X Windows applications without modifying the applications. Second, given these application models, we needed to support a methodology for translating graphical interfaces into nonvisual interfaces. This methodology should mimic the advantages of GUIs in an nonvisual presentation.

RESULTS

GUI Models

The de facto standard graphical user interface for Unix environments is the X Window System. X Windows is based on a client-server architecture where X applications communicate with a display server over a network protocol. This protocol is the lowest layer of the X hierarchy. Xlib and the Xt Intrinsics provide two programming interfaces to the X protocol. Xlib establishes the concept of events and provides support for drawing graphics and text. The Xt Intrinsics establishes the concept of widgets or programmable interface objects and provides a basic set of widgets. Most people who develop X Windows applications use X toolkits such as Motif or Athena. These toolkits build on top of the Xt Intrinsics and provide many generic interface objects or widgets

The Mercator architecture captures and models application GUIs while the graphical application is executing. We use multiple strategies to gather information about the application GUI, and to interface with the application. First, we use a protocol to communicate with the underlying X libraries upon which the application is based. This protocol is implemented by extending the Xt Intrinsics. We use the protocol to obtain high-level information (widget level) about the application interface. We also use a hook into the Xlib layer to monitor low-level interface information (X packets) which may not be expressed in terms of widgets.

Through our interaction with the Disability Access Committee on X (DACX)[1], we have worked with the X Consortium to extend the standard X Window System to include our access methods. From these two sources of information, we create an off-screen model of the application GUI based on the windows and widgets used by the application. We are then able to create an auditory presentation of the off-screen model, as well as substitute user keyboard input for mouse input expected by the application via the XTest extension.

Audio GUIs

The primary interface design question to be addressed in this work is, given a model for a graphical application interface, what corresponding interface do we present for blind computer users. Our work has examined the trade-offs between tactile and auditory presentations as well as determining the degree to which Mercator should mimic the existing user visual interface [2].

Mercator interfaces are made up of auditory interface components which are related to graphical interface components such as menus, buttons, dialog boxes and so on. Auditory icons are used to identify the auditory interface components and auditory filters are used to convey properties of those components.

Mercator provides a separate navigation method based on the hierarchy of the interface to replace the visual, spatial-oriented mouse navigation used in GUIs.We are also exploring the use of 3D spatialized sound to mimic the advantages of spatial organization used in graphical computing environments [3.].

DISCUSSION

As of April 1994, with the release of the newest version of X Windows (X11R6), the hooks necessary to build screenreaders for X Windows will be publically available. These hooks are based on the ongoing research of this group and on feedback from members of the DACX committee.

Since the beginning of this project, the primary goal of this work is to support the production of a commercial screenreader for X Windows. This work has not been conducted for research's sake alone, but with the intent of significantly affecting the accessibility of X Windows for people who are blind. Georgia Tech is currently working on establishing financial support for creating a commercial version of Mercator (Sonic X) for accessing Motif applications.

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SIG-12
Rural Rehabilitation

DEVELOPING A RESEARCH AGENDA TO INITIATE REHABILITATION SERVICES FOR MIGRANT AND SEASONAL FARMWORKERS

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ABSTRACT

The National Institute on Disability and Rehabilitation Research (NIDRR) has established "The Vocational Rehabilitation of Migrant and Seasonal Farmworkers With Disabilities" as a funding priority for fiscal years 1994-95. This initiative is very much overdue, but very timely for current initiatives taken by the Office of Rural Health Policy, and other rural health initiatives. This presentation will discuss methodologies to determine the descriptive statistics related to disabilities among MSFW, identify barriers, means to coordinate with other agencies, and identification of future rehabilitation needs for this population. Following participation, participants will be able to properly identify resources available for MSFW, and implement an appropriate rehabilitation agenda.

BACKGROUND

Approximately 1.3 to 6 million migrant and seasonal farmworkers (MSFW) participate in the national labor force. Identification obstructions exists as numbers either count, or fail to count casual hired farm labor, farm owners, and workers in agriculturally-related industries. Also, actual numbers of MSFW are difficult to obtain due to the transient nature of the population. This presents difficulties for rehabilitation professionals as mispercieived lack of client numbers, often results in misperceived lack of need for outreach. By developing strategies to identify MSFW rehabilitation professionals may find a population in need of rehabiltiation services, but inaccessible in past efforts.

The NIDRR notes MSFW experience higher rates of orthopedic disabilities, intestinal parasitic infestations, influenza, pneumonia, gastrointestinal diseases, and skin diseases than the national average person. For a larger part, these disabilities are preventable, and action is needed. The rehabilitation professional must incorporate prevention into a personal curriculum as prevention is the first step in disability management.

Also, half (52 percent) of the MSFW who apply for State rehabilitation services are accepted for services. Personal experiences reflect this is due to cultural differences between the client and counselor, language barriers, lack of understanding of the rehabilitation process on behalf of the client, and the transient nature of the MSFW. Rehabilitation professionals must identify and access these potential hindrances in the provision of services as these issues may be addressed by increasing cultural sensitivity.

OBJECTIVES

1. To assist the rehabilitation professional in identifying potential MSFW clients, and providing adequate services once MSFW clients are received.

2. To assist the rehabilitation professional in developing a methodology to identify demographic characteristics, service delivery issues, and future needs of MSFW with disabilities.

APPROACH

Using a combination of qualitative and quantitative methodologies, a research agenda will be discussed in obtaining data to ultimately be used in the development of prospective rehabilitation programs for MSFW with disabilities.

DISCUSSION

MSFW require vocational rehabilitation services, but are unable to obtain services due to language barriers and transportation blocks. Various health and rehabilitation services are available for MSFW and greater coordination between agencies is needed. Although the challenge is great, interest and proactive leadership on behalf of vocational counselors and other service providers may ensure MSFW receive needed vocational rehabilitation services.

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THE GRIPPER: A ONE-HANDED CATTLE CASTRATOR

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ABSTRACT

Seven years ago Mr. B experienced a left cerebrovascular accident and returned to his small cattle operation in southern Indiana after two months of outpatient therapy. He is now independent in all areas of his operation, but because of mild residual weakness in his right hand, he must rely on his neighboring farmers for assistance with cattle castration. This paper presents "The Gripper," a one-handed assistive technology device designed to substitute for Mr. B's upper extremity difficulties and allow him to castrate his cattle independently.

BACKGROUND

Mr. B is a left handed, 64 year old male who experienced a left cerebrovascular accident (CVA) at the age of 57 while working on the Alaskan pipeline. As a result of the CVA, he stayed in an Anchorage, Alaska hospital for four weeks. According to reports from Mr. B and his family, he experienced right hemiparesis, mild expressive aphasia, and cognitive deficits. After two months of outpatient therapy, Mr. B returned to his farm in Indiana and began a home exercise program. He reports he had functional return of his right upper and lower extremities and communication skills within nine months of the CVA. At present, Mr. B relates his only problems are mild residual weakness in his right hand and occasional difficulty with dynamic balance and memory.

With his wife and son, Mr. B maintains a 350 acre farm in southern Indiana with a herd of 60 Hereford and Angus cattle. As a crop farmer, Mr. B's duties include tilling the ground, discing, fertilizing, and seeding before harvesting in the fall. In the summer months his beef cattle responsibilities involve cutting, raking, and baling hay. The cold midwestern winters create additional problems for the cattle farmer as cattle are fed routinely, but water must be kept heated or the ice on frozen ponds broken. Additionally, heifers often need the help of the farmer to complete the birthing process. The castration of calves, an event in the early spring or late fall, is another important and necessary procedure for maintaining beef cattle.

In a survey designed to examine the needs of farmers and ranchers with spinal cord injuries (1), 96.4% of the respondents reported some level of difficulty in the castration/docking tails/clipping teeth category of farm/ranch activities; 83.9% of those responding actually needed help with the tasks. Cattle castration requires using the nonpreferred hand and arm to sustain a firm grasp and constant traction to the scrotal sac of the calf while incising the testes with the preferred hand. Although Mr. B is able to use his left hand to incise the testes, he does not have the necessary strength, endurance, nor muscle tone in his right upper extremity to grasp the scrotum and complete the task. At this time he is dependent on neighboring farmers to assist with this procedure. Since the culture of the farming community places great value on independent work performance, Mr. B states he is frequently depressed by his dependence in this activity.

Uniform Terminology for Occupational Therapy (2) divides human function into three occupational performance features: components, areas, and contexts. Occupational performance areas include activities of daily living, work and productive activities, and play/leisure activities; occupational performance components consist of sensorimotor, cognitive, and psychosocial skills; and occupational performance contexts include temporal aspects and environment. When looking at his inability to perform cattle castration in light of occupational performance, Mr. B's underlying difficulties in occupational performance sensorimotor subcomponents (strength, endurance, muscle tone, gross motor coordination, and bilateral integration) have not only negatively affected his occupational performance area of work and productive activities, but have also caused problems in his occupational performance psychosocial subcomponents (self-concept and role assumption) in his occupational performance contexts of home and farm.

A One-handed Cattle Castrator

OBJECTIVE

The objective of this case study is for Mr. B to be independent in all aspects of his cattle operation including cattle castration. He is not likely to regain the strength, endurance, and muscle tone in his right upper extremity, so a one-handed assistive technology device must be designed and fabricated to replace the function of his right arm and hand.

APPROACH

During the development phase of the assistive technology device for castrating cattle, Mr. B requested that the design include four characteristics:

1. The device must substitute for hand grasp.
2. The device must be easy to use with one hand.
3. The device must attach to Mr. B or to the floor
4. The device must be inexpensive to be easily replaced if misplaced or lost.

RESULTS

"The Gripper," a wire gripping cattle castration device, was designed using 1/16 inch steel stranded cable with a self-locking bracket at the top loop and a copper sleeve at the lower loop (see Figure 1). These materials were chosen because of durability, flexibility and cost effectiveness. The total price of "The Gripper" is $12.95.

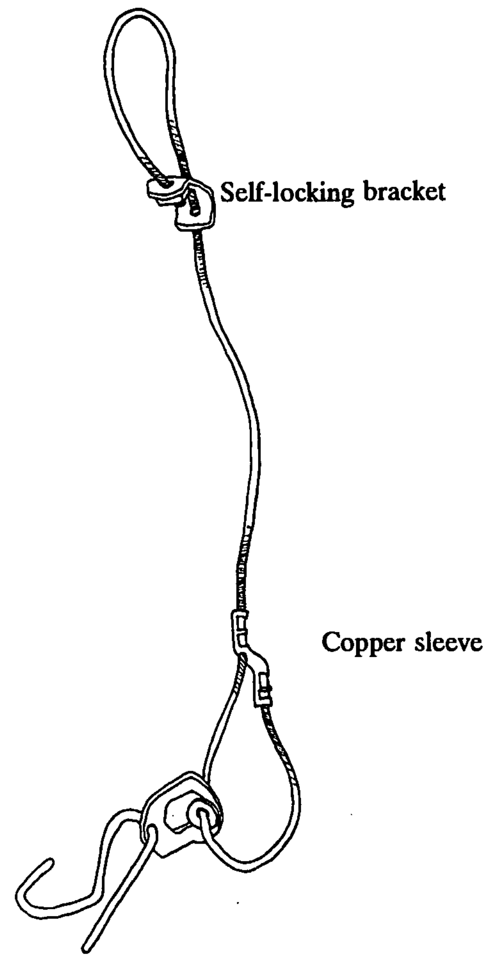

Figure 1. "The Gripper," A One-Handed Cattle Castrator

The top loop of "The Gripper," with the self-locking bracket, is designed to be adjustable. Before each castration, the self-locking bracket should be moved down the cable toward the copper sleeve to enlarge the circumference of the loop. After encircling the scrotum of the calf, the self-locking bracket may be moved up the cable toward the calf to decrease the circumference of the loop in order to sustain a firm grasp and constant traction to the scrotal sac. The copper sleeve secures the lower loop and allows the hook (attached to the lower loop) to be placed on Mr. B's belt or in a metal eyebolt set in the floor. Following castration, the device may be easily released for removal by sliding the self-locking bracket down the cable toward the copper sleeve (away from the calf) to enlarge the loop's circumference.

Mr. B started using "The Gripper" in the early spring of 1993 and reported successful use of the device. With the cattle castrating device, Mr. B is now independent in all aspects of his cattle farm and no longer relies on his neighboring farmers to assist him.

DISCUSSION

In developing "The Gripper," the designer was able to incorporate Mr. B's requested four characteristics: substituting for hand grasp, being easy to use with one hand, attaching to him or to the floor, and being inexpensive. By compensating for Mr. B's underlying difficulties in occupational performance sensorimotor subcomponents (strength, endurance, muscle tone, gross motor coordination, and bilateral integration) with "The Gripper," he no longer has problems in his occupational performance area of work and productive activities nor in his occupational performance psychosocial subcomponents.

In a cattle operation this device may be useful to many persons, particularly those with sensorimotor disabilities of the upper extremities. Frederick (3) listed handling livestock as one of the activities which may be difficult for people with cerebral palsy. Individuals with cerebral palsy resulting in diplegia or monoplegia may benefit from utilizing "The Gripper."

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An Affordable Lift System For Farmers With Mobility Impairments

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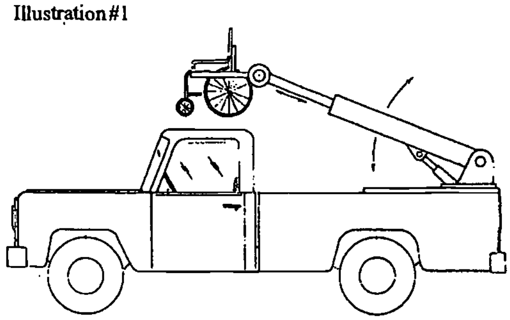
ABSTRACT
The purpose of this paper is to describe the development of a lift system to enable mobility impaired farmers to perform day-to-day activities safely and independently. The design process included the use of focus groups of potential users and input from the community of farmers with disabilities during the actual design. The FREEDOM LIFT system was developed based on an idea conceived by Howard Derksen as shown on illustration #1.

Illustration#1



The lift is designed to be installed onto the common half-ton pick-up truck and enables the farmer to enter the truck cab or any machinery (or building) area located up to eight feet above and twelve feet away from the truck.

DEDICATION
This paper is dedicated to the memory of the late Mr. Neale Abrey. Neale contributed honestly, tirelessly, and patiently to the development of the FREEDOM LIFT. He provided the authors with an insight into what it is like to farm with severe physical impairments by discussing the everyday problems that confront farmers with disabilities. Neale became our mentor and our friend.

INTRODUCTION
There are approximately one hundred and fifty individuals on the prairie provinces farming with severe mobility impairments. One of the greatest barriers faced is the difficulty reaching the operator's platform of the farm equipment. Until now solutions consisted of home-built devices or other means (ramps, loaders) to reach the required elevation. These solutions have, in many cases, been unsafe, unreliable and undignified. The methods used often expose the farmer and his or her assistant to further risk of injury.

The authors worked as a design team with the advice and assistance of Neale Abrey to develop a lift that could offer "freedom" and be mass produced and commercially available at an affordable price.

At the beginning of the project it was considered critical that the scope of the project be limited to allow completion within the available resources and time. The project objectives were confined to;
1. One group of potential users - farmers in wheelchairs or those requiring assistance in climbing ladders.
2. Typical non-motorized wheelchairs as requested by the user group.
3. Users who have the mechanical and physical ability to safely operate a mechanical lift.
4. Incorporate the use of a common North American 1/2 ton pick-up truck as the mount vehicle.

The lift system was to be designed with ample reserve strength and functions. Thus making it possible in the future to design new components for assembly to existing proven components to meet additional applications as they would be identified.

DESIGN AND DEVELOPMENT
The design of this product included the following six phases;
1. Selection of the required design criteria;
2. Preliminary engineering and design development;
3. Input from the community of farmers with disabilities;
4. Detailed engineering design;
5. Prototype construction, testing, revision;
6. Initial production run and installation for purchasers;
7. End-user use and evaluation.

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The design considerations were categorized into the following four categories;

a) Design features;
b) Applicable safety standards and regulations;
c) Physical characteristics;
d) Systems and controls.

Phase 1 of this project established criteria based on the author's perception of the problem at hand and developed the following list of features that were thought to be important.

Improved Independence

- the ability to mount and dismount farm machines unassisted.
- the ability to perform more maintenance in the farm workplace setting.
- the ability to enter and exit the vehicle on which the lift system is mounted.

Safety and Comfort

- slow, positive movement that will leave the operator assured of control and security.
- addresses the safety concerns of the owner, dealer and manufacturer.
- all CSA standards for related products reflected in the design.
- operation possible without the vehicle running.
- dealer installed, thus ensuring proper installation, assembly, inspection, testing, and operator instruction.

Compatibility

- causes no obstruction to other operators of the machinery who do not need the lift system.
- clean and quiet operation.
- useable in temperatures of +40C to -40C.
- fits within the outer dimensions of the mount vehicle.
- useable with popular makes and models of wheelchairs being used by farmers.
- adaptable to as many makes, models and sizes of pick-up trucks as possible.
- leaves a maximum portion of the truck box bed available for other uses.

Accessories

- the system should offer as many accessories to accommodate the disability of the potential operator and his/her equipment as is economically feasible.

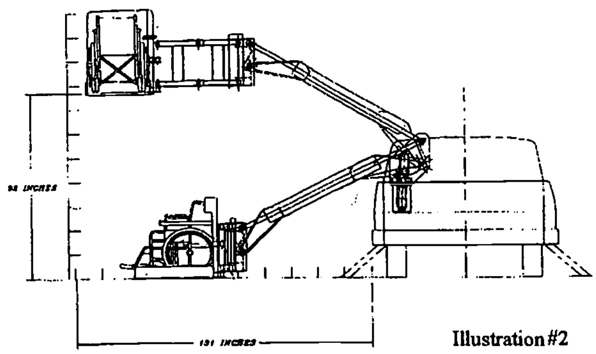

Illustration #2

With the basic design criteria established, the preliminary engineering design was developed as shown in illustration #2. These design drawings were used by the Saskatchewan Research Council to conduct a focus group meeting with 9 farmers with disabilities. The focus group was conducted without the design team present and confirmed the need for a commercially available lift system.

There was concern over the estimated retail price of $14,000; However, the group expressed a desire to see more features added to the product such as radio control. These desired features would obviously add to the cost and selling price of the lift system. A minority of the participants thought that the concern over price should not be a deterrent to the continuation of the development of the lift system.

A market survey was conducted using statistics available from the various support programs for farmers with disabilities in both the U.S.A. and Canada as well as the statistics available from the H.A.L.S. survey* conducted by Statistics Canada in 1987. It was determined that, although the target market was a limited market, the need was great enough to proceed with the project.

The detailed engineering design was completed using the C.A.D. design system. All drawings, bundle lists, and production lists were prepared by the fall of 1991. The Saskatchewan Research Council was contracted to conduct a finite element analysis of the main structural components. This served as a confirmation of the design as well as a double check for possible errors or oversights.

The first proto-type was constructed, assembled and tested during the fall of 1991. Testing of the proto-type included the following;

- operation by a disabled farmer,

* 1987 - Health and Activities Limitations Survey

- operation under extreme weather conditions,
- demonstrations for various persons involved in support and rehabilitation programs,
- introduction to the public of the proto-type at a University of Saskatchewan engineering show,
- proof test of the structure,
- stability test of the vehicle equipped with the lift system,
- a 50,000 lift cycle test.

Minor engineering changes and revision followed the proto-type testing phase and detailed drawings were revised to reflect all findings. The final "production" model of the FREEDOM LIFT was constructed and assembled during the winter and spring of 1992. Demonstrations were conducted for various farmers with disabilities in Western Canada. The FREEDOM LIFT was publicly introduced at Independence '92 in Vancouver in April of 1992. The lift was presented with an "Award of Excellence" in the Western Canadian Farm Progress Show in Regina, Sk. in June of 1992.

Active marketing began in July and August of 1992 resulting in the sale of enough units for spring delivery for a small production run to be manufactured from March to May of 1993. The first FREEDOM LIFTs were installed for purchasers during the month of June 1993 and were used throughout the active farming season in western Canada. Minor problems were experienced with only the first of installations. Subsequent deliveries have required no service calls, warranty problems, etc..

EVALUATION

A major successful aspect of this project was the ability to develop a major piece of equipment during a relatively short period of time.

Use of advice from the community of farmers with disabilities contributed to the development and made it possible to come up with the "right" product the first time. The FREEDOM LIFT has proven to be both safe and reliable largely due to the many years of theoretical and practical experience contributed by the authors of this paper. The first FREEDOM LIFT has been subjected to 55,000 lift cycles during formal tests and demonstrations. This is estimated to be the equivalent to 25 years of use under normal circumstances.

DISCUSSION

The most important aspect of any product developed for a specific market is the acceptance of the product by that market. Owners, when describing the FREEDOM LIFT, remark about the dependability, flexibility, compatibilty, and practicality of the design. The FREEDOM LIFT has proven to be a practical solution to the accessibility problems faced by farmers with mobility impairments.

The FREEDOM LIFT is currently being offered on the retail market to the farming community through a network of established dealerships throughout Canada and the mid-western United States. The retail price for a FREEDOM LIFT assembled, installed and adjusted is $18,800 (Canadian). There are no applicable taxes in Canada. The product can enter the U.S.A. without being charged duty.

The authors now are aware of many other non-farm uses for the technology developed during this project. The design team is currently concentrating on the use of the FREEDOM LIFT for offering accessibility to commuter aircraft used extensively in North America. The FREEDOM LIFT will enhance the lives of those with mobility impairments.

Patents for Canada and the U.S.A. are applied for and are pending.

ACKNOWLEDGEMENTS

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INTERNATIONAL AGRICULTURAL REHABILITATION

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ABSTRACT

Tens of thousands of U.S. and Canadian farmers and ranchers become disabled as a result of injuries, illnesses, and health problems. Most of these individuals want to remain in agricultural production, and, with some assistance, the majority can do so. Programs in the United States and Canada have demonstrated that people with disabilities could successfully continue their career in farming. If such initiatives have been successful in the U.S. and Canada, could additional agricultural rehabilitation efforts also be successful in other countries? The essential components to be included in the development of prospective international agricultural rehabilitation programs will be discussed. Following the presentation, participants will be able to identify essential components to be included in any prospective international agricultural rehabilitation program.

BACKGROUND

The international rehabilitation professional may play a vital role in enabling farmers with disabilities to continue farming. Components to be included in such an initiative include development of partnerships, engagement of volunteers, and development of technical expertise.

First, the development of partnerships is the key component in the development of any agricultural rehabilitation initiative. Often rehabilitation professionals have limited knowledge of agriculture and vice versa. By establishing linkages between agricultural and rehabilitation agencies, technical expertise from both fields may be utilized in modifying work tasks and/or equipment, or developing other rehabilitation plans.

Second, engagement of volunteers is important. Volunteers may contribute their time, skills, and materials to assist their rural neighbors with disabilities. Peers who have successfully accommodated disabilities may provide peer counseling and support to newly disabled farmers.

Third, technical expertise must be developed and disseminated. The majority of time in implementing a modification, such as a lift for a tractor, is spent conducting development activities such as design. By sharing information in accessible formats, future efforts to implement similar rehabilitation plans, such as the building of a tractor lift, may be less taxing in terms of product development.

OBJECTIVE

To assist the international rehabilitation professional in developing an agricultural rehabilitation program.

APPROACH

Using the National AgrAbility Project as a model, essential components to be included in the development of an agricultural rehabilitation program will be discussed.

DISCUSSION

Farming is a way of life for farmers with disabilities. This attitude crosses cultural and geographic boundaries. Rehabilitation and agricultural professionals, using the right components, may develop an agricultural rehabilitation program to address the rehabilitation need of farmers with disabilities.

ACKNOWLEDGEMENTS

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SIG-13
Assistive Robotics and Mechatronics

USE OF A REHABILITATION ROBOT IN A CLASSROOM SETTING

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Abstract

The Vocational Training Facility (VTF) has developed a three-workstation classroom as part of a project to test a new approach to the vocational training of students with physical disabilities. The three workstations are equipped with an array of devices and software to facilitate the access of curriculum and daily-living materials to the students. One of the devices in each workstation is the Desktop Vocational Assistant Robot (DeVAR), developed over a period of four years prior to VTF, and tested in clinical and vocational settings by users with high-level quadriplegia. This article describes the use of DeVAR in a classroom setting, and how the tasks and settings compare to previous environments.

Background

The Vocational Training Facility

The Vocational Training Facility (VTF) has developed and is evaluating a learning environment for students with physical disabilities. The goal is to eliminate the barriers of access to the tools and materials involved in learning and working [Hammel, et al., in press]. The curriculum, a 3-month intensive course on Desktop Publishing (DTP), is therefore entirely computer-based and controlled. Learning materials, programmed on an Apple Macintosh™, include a HyperCard™ stack for student training and performance assessment, computer-aided instruction (CAI) and laserdisc information controlled by the student and presented in real-time on the computer screen. Each student receives access software (e.g., Easy Access™, phone handling program, macros and utilities) and low to high technology access devices (e.g., mouthstick, trackball, adjustable keyboard mount, ultrasonic head-position control for cursor motion, voice recognition unit, tongue-touch keypad, voice-controlled robot). These ensure access to the learning materials and to items required for activities of daily living (ADLs) during the training sessions.

Student selection

The VTF is evaluating the effectiveness of the curriculum for students with high level quadriplegia (C2-C5). Students with low-level quadriplegia (C6-C8), who have limited arm function, and with paraplegia, who have complete hand and arm function, form the other two test subject groups. In total, the VTF will have trained six people from each of the three groups over a 24-month period. The robot is primarily intended to be used by the first group. This paper discusses the DeVAR-related results from the first four students with high-level quadriplegia, and its limited use by two students with low-level quadriplegia.

DeVAR tasks for VTF

Each of the three VTF workstations includes a Desktop Vocational Assistant Robot (DeVAR), which is composed of a Stäubli PUMA-260™ robot arm mounted on a 1 m. long overhead transverse track [Van der Loos, et al., 1989]. DeVAR has a servo-controlled gripper, an Otto-Bock Greifer, capable of grasping a 10 cm. wide, 1 kg. object with a 15 kg. grip. It can handle most common objects found on the desktop.

The vocational task set for VTF includes: Macintosh 3.5" diskette handling; laserdisc handling; paper handling from printer, to/from copystands, to/from holding slots and to an outbox; phone line dialing and answering via speakerphone or handset; and mouthstick handling. ADLs include: drink cup handling (or manipulating a flex straw from a pitcher); lunch preparation and presentation of a microwavable or cold meal; feeding using a spoon or fork; medication and throat lozenge selection and presentation using spoons; and nose scratching with a plastic fork. Each task has interactive phases to allow the user to select options and objects, and automatic phases for arm, track and gripper motion.

DeVAR is controlled through a discrete-word, speaker-dependent voice recognition unit, a Votan VPC-2100. Each user takes about 15 minutes to train a template file of the 60 vocabulary words, and typically trains a new file several times during the first week of learning to use the robot. Subsequently, single words are retrained on an as-needed basis.

Objective

Providing skills for empowerment

The most important qualitative objective of VTF is that each student becomes aware of opportunities previously out of reach, and acquires tools to begin exploration of personal vocational goals. Central to this VTF objective is the introduction to a vocational field (DTP) that has potential for personal growth, both economically and professionally. DTP is also a field for which data entry per se is not a determinant of overall job performance, an important aspect for competitiveness with other job applicants. Beyond this, the VTF teaches job skills and communication skills that supplement those learned during rehabilitation following the initial injury.

These factors are aimed at providing the knowledge to compete effectively in the job market, bolstering the incentive to rejoin the workforce, and strengthening the resolve to emerge from disability income support systems and become self-supportive.

Providing exposure to technology

A person with a disability reentering the workforce is often faced with the need to educate supervisors and colleagues on the job-specific functional aspects of the disability. Beyond communication skills, an important component of VTF is exposure to available methods, devices, adaptations, and computer-technology tools. The knowledge to help the employer in satisfying the "reasonable accommodation" requirement can be a great asset, and allows the implementation of a comfortable, functional work environment at the lowest cost and with the least waste of energy, time and resources.

The VTF exposes each student to the array of appropriate market-available tools and a smaller set of prototype devices and systems, such as DeVAR. Each student can assess, based on actual use, which devices are preferable and functional on a long-term basis. The VTF staff can also assess the value of the prototype devices and how they might be modified for greater functionality in the future.

Approach

Workstation set-up

The VTF has an established procedure for admitting students [Hammel & Van der Loos, 1991]. Once admitted, each student is interviewed by an occupational therapist and rehabilitation engineer prior to the start of the 12-week training session. The level of the student's function determines if DeVAR will be used. If not, the workstation components are arranged in accordance with the student's range of motion, wheelchair specifications, level of functional independence in task performance and personal preferences.

Robot programming

If DeVAR is used, the workstation itself is not modified substantially, since it is already arranged in accordance with the robot's range of motion and geometry. The set-up of DeVAR for VTF is not substantially different from previous configurations [Hammel, et al., 1992]. In particular, the user interface remains constant. However, certain aspects involving wheelchair height, task preference, and particular needs are discussed beforehand. Certain robot tasks involve bringing objects to the user, such as spoons, mouthstick and phone receiver. Each task is adjusted by the staff so that these items are brought to the correct positions. If additional tasks are needed, they are programmed, tested, and incorporated into the user interface.

Results

VTF users and environment

DeVAR was designed to replace an attendant, whose role was to perform user and robot set-up two to three times a day, and who was absent otherwise. In the VTF classroom, the continuous presence of a teacher means a *de facto* assistant at all times as a robot back-up. In addition, with its three workstations, the classroom is a more interactive setting than a single-user office environment. These differences in environment have resulted in differences in DeVAR usage. Overall, there is less reliance on DeVAR.

Differences between anticipated and actual usage

During the first year of VTF training sessions, DeVAR has been used by the students with high and low level quadriplegia in different ways than originally anticipated:

- Two of the students with low level quadriplegia had residual arm function, and used DeVAR for some tasks (i.e., medication and phone), and other, low-technology accommodations for others (e.g., paper handling, laserdiscs).
- Two students with high level quadriplegia have had a full-time attendant, and have used the robot and attendant interchangeably.
- Since the workstations are in a classroom and not an enclosed office, the ambient noise at times interferes with voice recognition in a manner not anticipated in the original design, causing periodic frustration. Experimentation with microphone placement was needed to reduce the influence of noise.
- To provide phone line access, the classroom has one shared line. Each DeVAR has a hands-off, built-in phone line handling feature, which works adequately for a single-line setting. However, it was not intended to be used cooperatively, causing problems when calls have to be transferred to one of the other workstations.
- None of the students wished to use the robot's lunch serving tasks on a routine basis. A total of only two meals have been served to date. Partly this was due to the limited menu (only liquid or canned servings such as soup, applesauce and chili), but mostly because lunch is a social event, a time of the day to get out of the classroom, take a break, and talk to people. Eating alone in the classroom was not acceptable.
- The medication and throat lozenge tasks were well-received, especially because the students could request these ADL tasks at any time during

the day, not just when someone happened to be near to help. However, the robot's drink task took more than 60 seconds to bring the cup to the user's mouth. This was deemed too slow a response due to the unpleasant taste of the medication. Therefore, most students used an always-accessible water pitcher and long straw.

Task changes requested by students

Most students with high or low level quadriplegia and adequate neck range of motion preferred a water pitcher and long rigid straw over a cup brought out of the cooler by the robot, especially when using medication. One user with limited neck motion asked for a 60 cm. long rubber tube, used as a flexible straw, to be inserted in the water pitcher. The robot then brought the other end of the tube, held in a clip, to his mouth. This was only marginally successful due to the high suction required.

Two other modifications involved telephone use. One user brought his own dialing and answering device, provided by the Pacific Bell Telephone Company, which was set up by his attendant in the morning. Another user wanted to set up a rolodex-type file on the Macintosh. The shareware program AddressBook™ was tried out temporarily, in conjunction with a modem, to dial out. This accommodation proved successful.

Discussion

Reasons for usage preference

None of the targeted DeVAR users elected to use the robot for all available tasks. Contributing factors were the classroom setting, continuous availability of assistance by the instructor and attendants, difficulties with the robot itself (e.g., voice recognition), and learning the DeVAR interface. The overriding reason for a lack of intensive DeVAR use, however, is that students are enrolled in the VTF primarily to learn DTP, and secondarily to acquire knowledge about market-available assistive devices. It is only a third project priority to expose students to prototype devices. It is of more immediate relevance to teach students about effective acquisition and use of attendant care in the workplace.

Future directions

The use of DeVAR in this new multi-workstation setting has shown that several modifications would make the robot easier to use. These include:

- integrating the interface with the primary computer, the Macintosh, so that reliance on voice recognition is no longer critical, and so that the interface adopts the Macintosh "look-and-feel";
- rethinking the phone interface, so that it is no longer a robot-mediated, but rather a Macintosh-controlled feature;
- adding sensors to the gripper to better accommodate objects slightly out of place.

It is not within the scope of the VTF to make these changes. However, the ongoing VA clinical evaluation of DeVAR, coordinated nationally by the VA Technology Transfer Section, will make its own recommendations in 1994 [Interim report: Cupo, 1993]. Future DeVAR development would therefore have two sources of extensive user feedback to consult in an effort to derive a market-ready, effective robotic assistant for students and office workers with severe physical disabilities.

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Impact of Mechatronic Systems as Vocational Enablers

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Abstract

Four mechatronic systems were designed and developed as vocational enablers. The prototypes were a result of a 1992 - 1993 university design course in collaboration with special education programs. This report will present the further evolution of the design prototypes and their continued impact on the special education environment and community vocational programs. The greatest impact has not been from the devices themselves. Rather, these prototypes provided a vehicle for discussion, needs analysis, further collaborative efforts, and a vision of expanded applications of enabling technology in the workplace.

Background

Four mechatronic systems intended as enabling technology to enhance special education vocational training were developed in 1992 - 1993 as university design course projects . The projects resulted from a collaboration between Wayne State University's (WSU) Department of Electrical and Computer Engineering and Wayne County Regional Educational Service Agency (WC RESA). The projects were described in two companion papers: Mechatronic Systems As Vocational Enablers For Persons With Severe Multiple Handicaps (Erlandson & Phelps, 1993) and A Partnership: University Electrical And Computer Engineering And Special Education (Phelps and Erlandson, 1993) presented at RESNA 1993.

Objective

The purpose of this paper is to:

- further update field test results;
- discuss the extensive impact of this University/Special Education partnership;
- answer the frequently posed question, whatever happens to student design projects?;
- disseminate information on the projects based on interest expressed through multiple phone calls regarding the projects to the authors over the past six months;
- encourage further discussion and networking among users of mechatronic and robotic systems in special education and vocational environments.

Approach

Twelve WSU electrical and computer engineering students produced four prototypes: a switch activated packaging dispenser, an assembly trainer, a dispenser for soap powders, and a switch activated turntable.

Sequential Task Trainer

A series of instrumented bins provide visual, auditory and/or vibratory feedback to prompt a student's time on-task and correct sequence of assembly or packaging jobs.
This project was a winner in the 1993 Easter Seal Student Design Competition (Deal, LoPorto & Rippy 1993).

Soap Dispenser

The device dispenses a predetermined amount of soap powder upon switch activation. The mechanism also provides auditory prompting and verbal reinforcement.

Switch Activated Turntable

This switch activated turntable is used in one of several ways. A common application is to move items from one person to another person. The turntable may also be set up to present only one item at a time to a student to begin training on assembly jobs. It may be used to bring multiple work items to a person who has limited reach or limited workspace, facilitating the ability to continue work for longer periods independently without restocking. Jigs may be placed on the turntable to stabilize items during assembly jobs for students with hemiplegia or difficulty using two hands together.

Switch Activated Packaging Dispenser

This device provides an opportunity for students who are switch users to participate in packaging jobs. The prototype was fabricated using vending machine coils. A dispensing mechanism drops a specified object into a container upon switch activation. Item selection may be controlled either by the user or automatically by the device.

In addition, as a demonstration project, robotic arms were incorporated into the designs of the measuring dispenser and the turntable load supplies and remove completed work.

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Results
Special education students with cognitive impairments demonstrated decreased dependence on staff for prompting and cueing while using these prototypes. The result is increased productivity and on-task behavior. Staff report an apparent increase in self-esteem and an enjoyment of active participation in tasks the students were previously unable to accomplish. The systems have been in place a significant period of time to rule out a novelty effect. The students continue to be motivated and excited to use the devices.

Staff report there remains considerable set-up time required for use of the devices. Staff with limited computer knowledge are reluctant to use the systems requiring computer entry. As further discussed below, a re-engineered concept prototype was developed based on the field trial experiences with the first prototype. The new prototype incorporates the desired features of the first generation and addresses the identified setup problems .

The switch activated turntable did not have the voice output built into it as did the other three devices. It was determined the voice output was indeed a critical factor for improving student success and decreasing staff interventions. Based on field trial experience with the turntable, a second generation turntable was designed and built. to incorporate the voice output feature.

The MICROBOT TeachMover robotic arm proved unreliable for this application. There was no on site technical support available at the school to provide adjustments. The necessary readjustments and re-initializations were too complex and time consuming for school staff. The RTX is capable of multiple functions beyond the simple pick and place operations utilized in this project, and as such is not a particularly cost effective utilization of this resource.

Special education staff discovered that the jigs and dispensers created for the robot, when used by students, allowed students who could not successfully complete the job before, to perform the task. The jigs and dispensers present items in the same place and orientation every time and present only one item at a time . This allows a task to be cognitively and motorically simpler. By designing a work environment for the robot, essentially a blind, one armed system, the result is a highly structured environment that may open jobs to individuals with cognitive limitations who previously could not do the jobs. Interestingly, this is consistent with the experience of General Motors and a host of other companies that have found that designing some small to medium assembly processes for robotic assemblies yields assembly processes that are so highly structured that it may be cheaper for people to do the assembly than the robots (Noblett, 1993).

The experience with these devices continues to change and expand the view of special education staff and job developers regarding the range and type of jobs in which students with severe impairments may be able to successfully participate.

Evolution of the prototypes
Two WC RESA sponsored activities funded expansion of the projects. A WC RESA Elementary Secondary Education Act mini-grant supported fabrication of a second generation sequential task trainer and the switch activated turntable with voice output. The grant contracted two of the WSU students to fabricate second generations of the prototypes. These two devices are currently available from a lending library to the 34 local school districts served by WC RESA as well as to community agencies serving the district's graduates.

ADAMLAB (Adaptive Devices Applied Methods Laboratory) is a unique component of WC RESA. ADAMLAB designs and contracts the manufacture of electronic communication systems and related materials for use by low-incidence special education students. ADAMLAB's flagship product is the Wolf Voice Output Communication Aid. ADAMLAB provides technical support and funding for maintenance of the original prototypes. They are currently investigating the feasibility of a re-engineered sequential task trainer. ADAMLAB's version is a stand alone unit with an on board microcontroller and voice output. This takes the prototype from a concept prototype to a production prototype with manufacturable housings, sensor arrays, and packaging. In addition, ADAMLAB contracted one former WSU student to design and fabricate a system for switch controlled placement of letters into envelopes, and is considering a bid from a former student to augment the packaging dispenser prototype with a conveyor system to move packaged items from the dispenser area.

Outcomes for University Students
All the participating students were introduced to the concepts of universal design, an experience they report as valuable for further course work and employment. One student is pursuing a masters degree in Electrical Engineering with an emphasis

in biomedical engineering. Another student has established a design and fabrication company and is considering graduate work in biomedical engineering.

Discussion

Mechatronic systems have clearly demonstrated potential to enable students with cognitive and physical impairments to experience success in vocational training situations. In addition, service delivery is expanding and evolving based on these experiences.

Both authors are active advocates for dissemination of information and further development of these systems. As such, the authors met with an interagency transition council, composed of local school personnel, advocacy groups, parents, and community agencies to disseminate project results and discuss further needs and applications. Based on the needs identified by the interagency council, the authors are coordinating a series of meetings to bring engineering resources from local businesses including Ford Motor Company and General Motors to the special education and community vocational placement agencies.

Several short term projects have been initiated as a result of the meetings. We recognized that the original application of the RTX was more a demonstration of technology for the WC RESA staff then a cost/effective application. Based on this demonstration the RTX is currently being reprogrammed to assist an individual with severe disabilities to complete an inspection and packaging job at a community business. It remains to be seen if this application will be cost effective. A Ford engineer is consulting with one of the community agencies to improve a packaging operation, and those efforts will be enhanced by WSU students enrolled in the current design course. Another current design course project includes workplace restructuring involving an industrial engineer and a local school facility. The last project is based on a philosophical shift, away from one-to-one individualized accommodations, toward generic workplace restructuring to enable a broad range of individuals with disabilities to be more successful at a chosen job.

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THE DESIGN OF AN INTEGRATED INTERFACE TO AN EDUCATIONAL ROBOTIC SYSTEM

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Abstract

This paper describes the design and development of an integrated interface to a robotically-aided education environment for children with physical disabilities. The design and development of the education robotic system emphasizes the use of commercially available devices to reduce the cost and to facilitate the carryover to the use of other assistive devices. The input devices for the robotic system are interchangeable to minimize the cognitive load placed on the child and to maximize system flexibility. The ultimate goal of this research is to provide an equal opportunity education for mainstreaming children with severe physical disabilities.

Background

Throughout the U.S., children with severe physical disabilities are more frequently an integral part of educational environments that promote academic and cognitive growth. To advance this process it is essential that they are able to interact with robust problem solving environments which challenge their cognitive skills and increase their academic prowess. If the aforementioned environment contained a robotic device, a child with a physical disability would be allowed to directly experience important aspects and concepts of their physical world, which they have previously been unable to explore. For this reason, children with disabilities may discover significant benefits through the proper development and implementation of robotic devices in their educational environments.

Statement of the Problem

Using a computer to interactively control a robot to perform a variety of tasks is a daunting undertaking. Individuals who have a physical disability are often unable to use a standard mouse or keyboard and are at an extreme disadvantage when interacting with a computer system. Although applications and devices have been developed to allow individuals with physical disabilities to use computer systems, using these items simultaneously and interchangeably is not always easy or possible. The user interfaces to these computer systems must be affordable and adaptable to a wide range of disabilities.

Rationale

The design of an integrated interface between the education robot and an child who is physically disabled is the preeminent goal of this research. It is necessary for the educational robotic system to allow the straightforward design of user interfaces to the robot, so that teachers and therapists can alter the interface to changing needs and tasks. Moreover, it is vital that the interface be capable of handling a variety of devices and alternative mice interchangeably, so that the system is adaptable to a variety of individuals with disabilities [2].

Design/Development

The educational goal of this research is the design and development of a robotically-aided educational environment for students who are physically disabled. To minimize the software and hardware development costs, commercially available applications and devices were utilized whenever possible in the robotically-aided educational environment. Commercially available devices and applications are often more durable, adaptable, and reliable due to their use by a larger population. The prototype educational robotic system uses a UMI RTX robot. The RTX was selected for its previous performance history in clinical rehabilitation settings and its low maintenance record.

The Cambridge University Robot Language (CURL) for Windows was the software selected to manage the interface to the RTX. CURL has been developed at Cambridge University and was specifically designed for applications in rehabilitation [1]. CURL provides three methods for controlling the RTX, which are called "direct", "command" and "procedures". "Direct" control allows the manipulation of the RTX's individual joints through the click of a button with the mouse or by a series of keyboard commands. With "command" control the user is permitted to use the CURL commands to control the RTX. The "procedures" control mode allows the user to execute pre-programmed procedures, which are made up of a series of CURL commands. Since CURL is limited to keyboard and mouse input, additional Microsoft Windows applications were necessary to allow non-keyboard users full control of CURL.

Modified keyboards or switch access applications can be used to provide the user with alternative access to CURL. The switch access applications evaluated were WiViK 2 Scan (Windows Virtual Keyboard) and SAW (Switch Access for Windows). WiViK 2 Scan allows the design of a virtual keyboard on the screen and handles up to 5 switch inputs via the PRC Switch Connection Box from the Prentke Romich Company. The PRC Switch Connection Box handles input from 5 single switches, 1 dual switch, or 1 multi switch (standard 9-pin joystick switch). The ability to use all of these different types of switches with the PRC Switch Connection Box conforms to the idea of device interchangeability in the robotically-aided educational environment. SAW also allows the design of virtual keyboards, but only handles up to 2 switch input to Windows. WiViK 2 Scan and SAW were evaluated using a dual switch sip/puff device and numerous single switch devices, including a leaf switch, a pillow switch, a grab switch and 4 jelly bean switches. Some TASH 5 switch devices including joystick with pad, joystick with push, Star, Wafer, and Penta, were used in the evaluation of WiViK 2 Scan. After evaluating both applications, WiViK 2 Scan was chosen as the access application, because of the 5 switch input capability, directed scanning via a joystick switch and the capability to select an item by using the dwell feature. The evaluation also revealed that SAW is unable to work with some mouse drivers, such as the driver that is provided for the UnMouse™. This deficiency with SAW compromises the concept of interchangeability of devices in the robotically-aided educational environment.

Numerous interface devices were evaluated to determine which of them work best for an individual who has a physical disability. The alternative mice evaluated with WiViK 2 Scan included the UnMouse™, MouseMan™ Cordless Radio Mouse, Thumbelina Trackball, PC Stylus™, and GyroMouse™. The interface to the system was enhanced further with the addition of an IntelliKeys keyboard and a ClearTek™ touch screen from MicroTouch.

IntelliKeys, which was used as an alternative keyboard device, allows custom overlays to be created by the user. Currently there are two ways to make an IntelliKeys overlay for an IBM compatible computer. The first method is to use an editor to create a text file in a very specific format. That text file must then be transferred to the IntelliKeys using a program provided by IntelliTools. The second method requires an Apple Macintosh computer. On an Apple Macintosh the IntelliKeys overlays can be created with an interactive program called Overlay Maker™. This application will create a print of your overlay to be placed on the IntelliKeys and will generate the text file in the specific IntelliKeys format. The IntelliKeys text files are transferable between the two systems and IntelliKeys intends to eventually release an IBM compatible version of the Overlay Maker™. The ability to have an identical layout on the IntelliKeys and WiViK is important to the future therapeutic assessment of individuals, since it provides a common ground for comparing IntelliKeys and WiViK 2 Scan. Identical layouts can also significantly reduce the cognitive load placed on the user to learn a new interface setup when determining which input device is best for a given individual.

Evaluation

Trial studies of the WiViK 2 Scan & IntelliKeys interfaces controlling CURL have been done with 5 children with disabilities at the A.I. duPont Hospital. In these trial studies finger painting was chosen as the task to be performed by the educational robotic system. It was felt that the task of finger painting would not present the child with too heavy of a cognitive load, but would provide significant insight into the user interface needs of an individual with a physical disability. In this evaluation we identified a possible limitation of the UnMouse™ from MicroTouch, which is a touch-sensitive tablet. Since the UnMouse™ pad requires direct human contact or a conductive instrument, a user can not use a mouthstick with this interface device. The same was found to be true for the ClearTek™ touch screen from MicroTouch. It may be possible to use a mouthstick if the mouthstick were conductive, but we did not attempt to design such a mouthstick for the obvious safety reasons. These ongoing trials are an integral part of the interface design and development process.

Discussion

In addition to the variety of input devices already discussed in this paper, the HeadMaster and a voice recognition application called VoiceType™ Control for Windows will also be integrated into the robotic educational system. With such a variety of input devices, a school therapist will be able to first use the system to determine which input device a child can use to maximize success with assistive technology. The same input device, whether it be single switch, HeadMaster, or voice control, can then be used for all computer applications and other assistive devices.

To successfully utilize the robotic workstation as an effective educational enhancement tool, the various facets of the robotic environment must eventually be integrated with the educational goals of student. To accomplish this, in the future the educational robotic system will be setup as a robotically-aided science education environment [4]. Overlays for science curriculum experiments will be developed for both the IntelliKeys keyboard and WiViK 2 Scan. Teachers will be able to call up the appropriate program for the day's curriculum, plug in the input device that a child is most successful with and proceed with the hands-on or "robot-on" science experiment. In this way, a child who is severely physically disabled can take part in an equal opportunity education environment.

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EVALUATION OF THE RAID WORKSTATION

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ABSTRACT

The RAID (Robot to Assist the Integration of Disabled and Elderly) demonstrator is a prototype robotic workstation intended for wheelchair users for vocational use in an office environment. A group of potential users has been involved throughout the project to comment on the design and functionality of the workstation. This paper describes the evaluation process of the workstation together with the conclusions drawn.

BACKGROUND

The RAID workstation was developed during the pilot phase of TIDE (Technology Initiative for the Disabled and Elderly), an EC initiative, as one of 21 projects [1]. Companies and universities from the UK, France and Sweden participated.

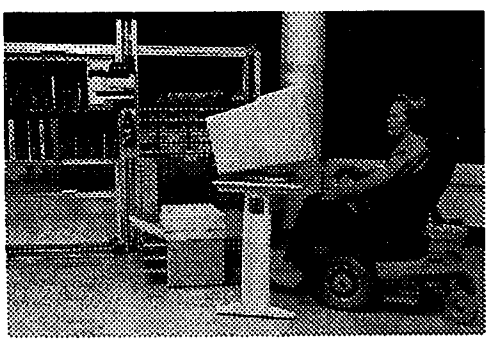

Figure 1. The RAID workstation

As found in the work and evaluation of the DeVAR (Desktop Vocational Assistant Robot) system [2], robotics technology can assist in returning the severely physically disabled to productive employment. The target group for the RAID prototype is wheelchair users with limited upper limb functions. The workstation is intended to support this group in computer-based office tasks in handling paper, books, different kinds of computer media and beverages. For this prototype version we chose CAD (Computer Aided Design) because it is one of the most demanding tasks when it comes to accessing reference material.

OBJECTIVE

In order to develop a product which is accepted by the potentional users such a group has been consulted throughout the project. Their main function has been to formulate the user requirements and to actually perform the evaluation of the prototype.

When it comes to new technical devices, such as robots which are often considered rather abstract, the hard part for the user is to find out what he/she really wants and needs. To actually try and evaluate a prototype version makes the development of the device into an iterative process. The results from the evaluation of the demonstrator version act as input to further development of the workstation. The aim is to make RAID into a commercial product.

The questions to be answered during the evaluation were:

- How easy is it to understand and to use the user interface?
- Does the workstation perform the tasks at an acceptable level for our target group?
- How well does the workstation adapt to the needs of the potential users?
- What are the opinions of the secondary users, i.e. those who program, give technical support, train or assist?

METHOD

Evaluators

From a user group of seven, only two were chosen to carry out the evaluation mainly due to the time limitation of only two weeks.

User #1 was a 45-year-old male quadriplegic. He has full control of head movements but little hand control. His normal input method is sip and puff via a scanning hardware keyboard. We had to adjust the RAID-joystick by mounting a knob-like ball on it for him to use it as a chin joystick .

User #2 was a 37-year-old female quadriplegic. She has good control of her right hand/arm but no finger function. Her normal input method is a stick with which she makes binary keystrokes on a normal keyboard and controls a rollerball for mouse movements. These prerequisites lead us to mount a U-shaped stick on the RAID-joystick for her.

Evaluation process

The evaluation was divided into three parts:

- evaluation of the system on a task and interface level
- evaluation of RAID functionality for a CAD-application
- evaluation of changes needed to meet the evaluators' individual needs

User interface

The input devices chosen for the workstation were a joystick mouse and an on-screen keyboard (WiVik). Initially the input device were evaluated and optimized. The users' typing speed and mouse control ability were also measured and compared with the users' normally used input devices and with that of

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non-disabled users. In this way it would be possible to compensate for a low input speed when measuring the performance of the robot tasks. During this time the users were also trained in the essentials of the Windows concept.

We chose to use preprogrammed tasks, as opposed to controlling the robot in direct mode like with the Manus manipulator [3], to keep the user interface as simple as possible. Direct mode was only used when an error occurred and the robot needed to be moved to be able to continue its task execution. The tasks were chosen through a menu-based interface running in Windows. The different menus were organized in a hierarchical manner where each menu consisted of a number of buttons.

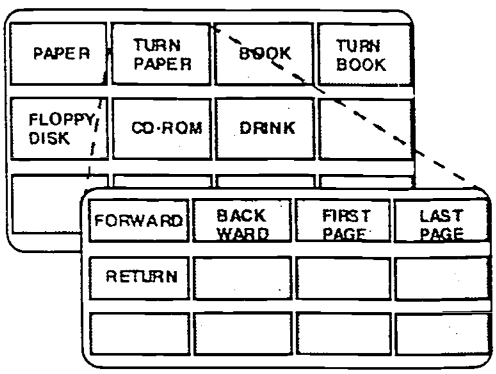

Figure 2. Schematic picture of a two-level menu

Task evaluation
For the task evaluation we used a questionnaire which was filled out after each task was perfomed a number of times:

1. Can you describe the task in a few words ?
2. Was it difficult to distinguish this task from the others, i.e. was it hard to choose the task specified?
3. Was it difficult to understand the purpose of the task ?
4. How many times was the task performed ?
5. How many times did RAID succeed in performing the task ?
6. Was it difficult to perform the task ?
7. If so what was difficult?
8. Was it possible to do everything stated in the task description ?
9. If not which part/s was/were not possible to do ?
10. How was the speed of the task performance ?
11. Did you feel safe during the task ?
12. Was the task performance reliable ?
13. Do you need to perform this task regularly ?
14. If so does RAID perform it satisfactorily ?
15. On a scale from 1-10 how do you rate the performance of the task ?
16. What needs to be improved with this task?

The RAID functionality for CAD-application was to be evaluated by performing sequences of tasks to simulate a work day.

The last part of the evaluation was documented through a questionnaire stating the users' opinions on the overall performance of the workstation.

RESULTS

Input device
The results from the evaluation of the input devices showed a rather drastic decrease in speed compared to the users' normally used control method. It was most obvious when typing a text using the on-screen keyboard. The decrease in speed was compensated for in the evaluation of the task performance.

User interface
Both of the users found the user interface to be easy to use and understand. The tasks are simple and high level and it is the operator's responsibility to, for example, find empty compartments or avoid placing more than one book on the readerboard. They felt that they had control of the robot including the possibility to stop the task sequence if desired. One objection though was to the way the menus were organized which is dependant on the programming.

The users stated a wish to be able to work parallel with the robot, with, for example, a word processor in Windows. This was, however, not possible in the prototype version.

Task performance
The main objection from the users was the reliability in the performing of the tasks. Their major concern was the paper and book handling since these tasks are required in their work. The users pointed out the difference between recoverable and unrecoverable errors. A task, such as stapling a pile of paper, which results in a recoverable error can be performed time after time until it succeeds while an unrecoverable error, such as dropping paper on the floor, requires outside assitance and is unacceptable.

Due to lack of reliability in the performance of seperate tasks, like failing to close a book or failing to put a pile of paper back in a compartment, it was not possible to execute sequences of tasks. This meant we were unable to run and evaluate the CAD-simulation tasks since they consisted of task sequences.

The users stated that if the workstation were to support them in a job situation the speed of the tasks execution needed to be increased. As for now it was a big difference for the users to actually be able to perform the task, for example turn the pages in a book, without any outside assistance.

General opinion
The overall impression of the workstation was positive both regarding size and appearance. User #2 wanted a smaller version to be able to fit into her home. She also wanted to use another input method, like the one she is using today. User #1 appreciated the ability to read both sides of a piece of paper. As for now he has to rely on his assistants to turn the pages.

Evaluation of the RAID workstation

The users felt safe during the execution of the tasks knowing that it was possible to stop the robot at any time through the command software.

Secondary users
The flexibility of the prototype is very limited. If for example the angle of the readerboard is changed, reprogramming is necessary. It should be possible for a rehabilitation center to choose the complexity and size of a workstation to meet individual requests.

The training of the users has been no problem since the world modelling of RAID is fairly simple. It is possible though, that a more graphical user interface would increase the level of autonomy.

DISCUSSION

The prototype version RAID was well accepted by the users. It addresses a need of this group of disabled to be able to find a vocation and therein attain a certain level of autonomy. The results from the evaluation are very valuable in the continuation and further development of this project. One major issue will be reliabilityin bringing the workstation to a commercial standard.

During the evaluation it was found that the input device should not be a part of the workstation. It is preferable if the rehabilitation centre responsible for the installation can choose the best and for them well-known input device. Consequently the robot control software should be in a well-known environment such as Windows or Macintosh. Standard input methods will then work together with the workstation as well.

As the performance of the workstation improves the user group can be broadened. If available technology for adaptation of the input device is used, people with a physical disability that makes it difficult for them to perform various handling tasks may be incorporated in the group of potentional users. Hence extensive user trials, with a broader user group, will take place in the three participating countries where the main focus will be on running scenarios and not only separate robot tasks.

ACKNOWLEDGEMENTS

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EYE MOVEMENT CONTROL OF THE MANUS MANIPULATOR

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ABSTRACT

This study investigates the feasibility of using eye movements to control a robotic manipulator. An interface has been developed between the BioMuse, a commercially available eye tracking device, and the MANUS, a wheelchair mounted robotic arm. Preliminary data has been collected indicating that the system can be used to target command zones in the field of view which will be used to command the arm. In the long session, participants did not report signs of fatigue. Clinical trials are planned to further evaluate the system.

BACKGROUND

Developments in the area of rehabilitation robotics offer new opportunities to people with disabilities who are often hampered in their daily activities, and limited in their interaction with their environment. However, limitations in current interfaces to these devices reduce their accessibility for people who could most benefit from their use [1].

Eye tracking has been successfully used in the area of augmentative communication [2]. In most of these applications, an external light source and camera are mounted near a computer, and the position of the eyes is used to select a key on a visual keyboard.

RESEARCH QUESTION

This study aims to answer the question "Is it feasible to use eye movements to control a mobile rehabilitation robot?". The question can be broken down into several criteria:

- can the eyes target command zones in the field of view
- can the user hold his/her gaze in a given command zone
- can these command zones be used to control a robotic arm
- can a person control a robot arm without undue fatigue

This study examines the issue of feasibility. It does not attempt to determine the optimal control configuration. That is left as future work.

METHOD

System Components

The system consists of a computer program which translates eye position information from the BioMuse eye tracker into command inputs to the MANUS robotic arm (see Figure 1). It also controls the computer exercises, and records performance measurements.

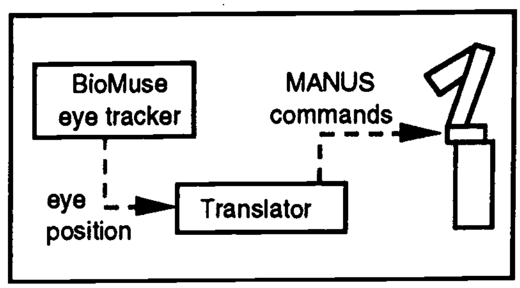

Figure 1 - System Overview

The BioMuse is a biosignal processing platform[1]. It uses electro-oculography (EOG) to monitor the position of the eyes. No external light sources or cameras are required, making the system suitable for a mobile, wheelchair-mounted robotic arm. The information is transmitted via a serial cable to the PC. Software libraries are provided to allow the user to write applications to read and interpret the data.

The MANUS manipulator is a wheelchair-mounted robotic arm. The standard interface is a 4x4 keypad. End-point control is offered through XYZ and roll/pitch/yaw commands, and the control configuration is user programmable.

Mapping

In this system, the position of the robot gripper does not actually track the movement of the eyes. Rather, the eyes are used to activate 'switches' defined by command zones in the field of view. When the user's gaze is detected in a command zone, the corresponding command is sent to the robot. The command is active as long as the eyes are activating the switch.

Two schemes are used, a simple one, and a complex one (see Figure 2). In the case of the simple field of view, two modes are needed: one to

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access the vertical plane of motion, another for the horizontal. In the horizontal plane of motion, the up and down command zones map to in and out motions of the arm. In the complex field of view, the short up and down are used for up and down motions of the arm, and the long up and down are used for in and out motions of the arm.

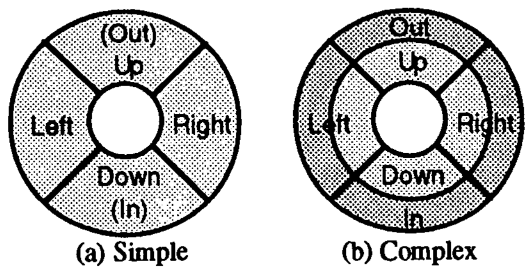

Figure 2 - Command zones in the field of view

During the development of the system, a possible safety issue was raised. Because the user must shift their gaze away from the task at hand to activate a command zone, they must rely on their peripheral vision to monitor the progress of the robot. An alternative method would allow the user to maintain their gaze on the task at hand, while moving the head and affecting a movement of the eyes. This method will also be evaluated.

Evaluation

Studies have been designed to evaluate the performance of this control interface, comparing it to other control input devices suitable for users with limited or no hand function.

Evaluation of the system will be performed in two phases:

1) a computer exercise which will evaluate the user's ability to target the command zones with their eyes
2) tasks performed with the MANUS arm

The computer simulation will present the user with targets appearing on the screen in locations corresponding to the command zones in the field of view. The user 'hits' the target by directing their gaze at the command zone. The computer software will measure:

1) the time to hit the target
2) the number of miss hits
3) the absolute value of the trajectory length

Tests with the MANUS arm will require the user to manipulate objects in space. The tasks will range in difficulty from knocking objects over to placing objects into pegboard-style holes.

Performance with the eye movement controller will be compared to performance on the same tests using two other interfaces: the Nintendo Hands-Free Controller, and the Spaceball, an isometric joystick. While the second interface is not suitable for a user with no hand function, it can be used by someone with limited or weak hand function, since no motion is required, only force, and very small forces can be detected.

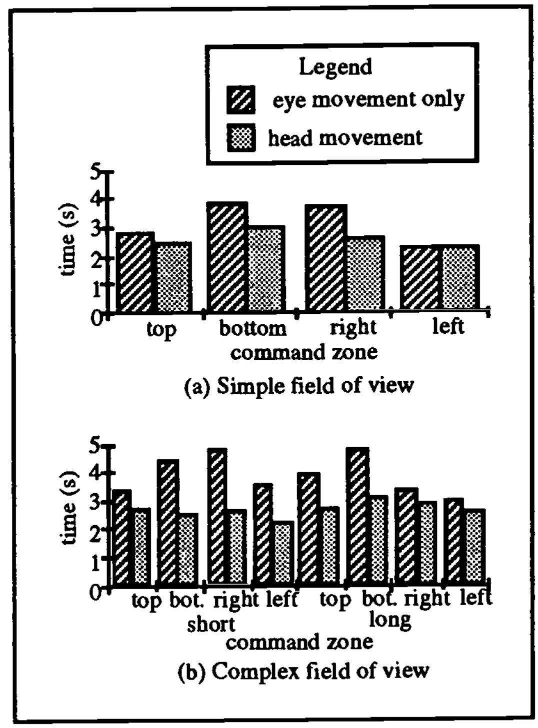

Figure 3 - Average time to hit target

RESULTS

Preliminary data was collected from four participants. The exercises evaluated each participant's ability to use the eye tracker to target command zones in the field of view, for both the simple and complex mappings. Eye movements and head movements were evaluated separately.

Figure 3 shows the average time taken to 'hit' each zone for the various tests. The averages are:

simple	eyes only	3.82 s,	stdev 1.48
	head	2.60 s,	stdev 0.58
complex	eyes only	3.97 s,	stdev 2.02
	head	2.56 s,	stdev 0.74

Using a t-test, comparisons were made between eyes only and head movements, for both simple and complex field of view, and between the simple and complex field of view, for both eyes only, and head movements. For the comparison of eyes only to head movements, the both fields of view achieved significance at the $p<0.01$ level. For the comparison of simple and complex field of view, neither eye movements only nor head movements showed statistically significant differences.

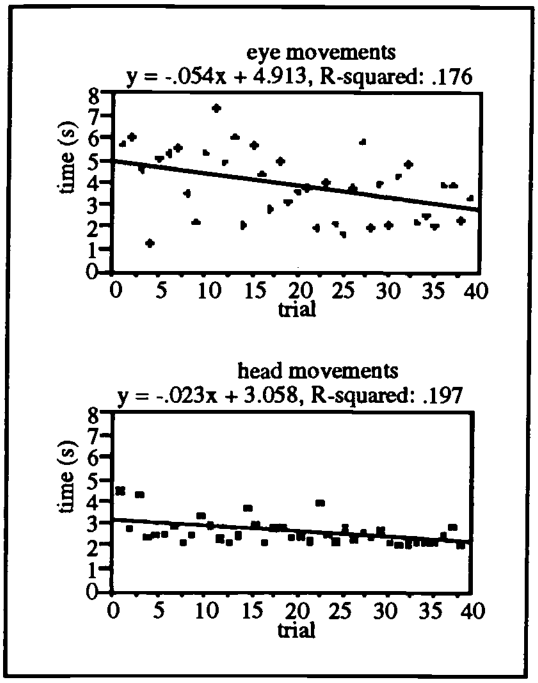

Figure 4 - Time to hit target - simple field of view

Figures 4 and 5 show the average time taken to 'hit' a target for each trial in a session. The line of regression is indicated.

DISCUSSION

The preliminary data indicates that the complex field of view does not increase the difficulty of hitting a target, however the use of head movements does improve performance. As well, in most cases, the time taken to hit the target decreases over the course of a single session. This is likely a learning effect. With the more complex field of view, the learning effect is less pronounced.

The participants commented that in general, they did not find the process tiring. Initial novelty of the system resulted in reduced blinking due to concentration, but this effect was reduced in the second session.

FUTURE WORK

Further studies will collect data from 18 participants, and compare the results found with the eye movement controller to those found with the alternative interfaces. Feasibility of the interface will be based on the comparison to the other interfaces.

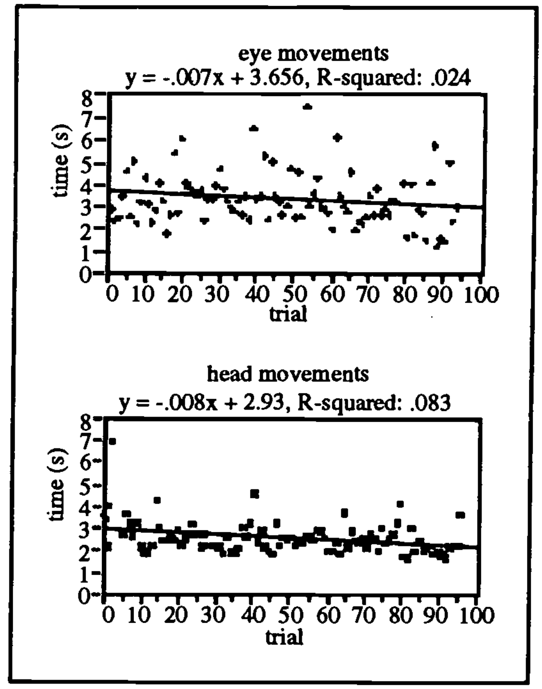

Figure 5 - Time to hit target - complex field of view

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EMG PATTERN ANALYSIS FOR PROSTHESIS ARM CONTROL

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ABSTRACT

In this paper, Myoelectric Signals (EMG) were used for prosthesis arm control. We present a new approach to decrease classification error rates which are caused by artifacts and a method to make decomposition by introducing fuzzy reasoning which is based on the information of muscle characteristics and EMG signal in a decision space of a artificial neural network's output. Since the suggested approaches are proper to prostheesis arm control and dynamic motion control, the result of pattern classification could be directly applied to control systems.

BACKGROUND

In developing pattern classifiers, the learning and training of the classifiers to find equivalent features of motions have limited the numbers of motions[1][5]. So, it is necessary for multidegree of freedom arm prosthesis to have continuous decision spaces. It has been common to overcome these difficulties using linear interpolation[3] between reference motions that were learned by classifiers in a decision space. In control of multidegrees of freedom arm prosthesis using the EMG signal, it causes muscle fatigue to move the arm in the limited training coordinate, the model of muscle movement command should be modeled in a linear system and complex inverse Jacobian should be calculated for resolved motion rate control in a linear interpolation of limited coordinates.

And, the Eucledian distance measure has a problem that increases classification error rates when its output is obscure. What we'd like to suggest are a method containing fuzzy reasoning using information of muscle movement to a decision space for a robustness of classification and an alternative way of nonlinear mapping using fuzzy decomposition.

RESEARCH QUESTIONS

The motive which had begun this research were based on these questions. The first one was that there might be a any new analysis approach for prosthesis arm control, the second was how much reliance a linear interpolation has in a decision space, and the third one was how we analyze arm movements which are laid between classes for prosthesis arm control using the EMG signal.

METHOD

The system configuration is shown in fig.1 The EMG signals were collected through surface electrodes on the biceps and triceps. The features like IAV and Zero crossings were extracted to the train and recall artificial neural networks, Multilayer perceptron. And the outputs of it were applied to fuzzy reasoning logic membership function which was the next processing unit of MLP and was based on the previous information of muscle movement. To make rules of the system's

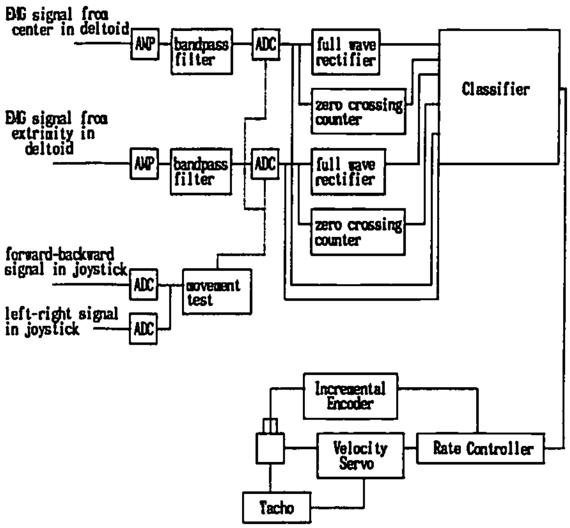

Fig.1 System Configuration

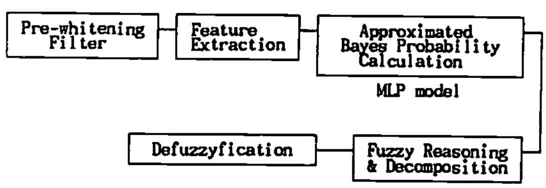

Fig.2 Configuration of CDC

characteristics, we verified the classified results, and input it to a rate controller after decomposing it. In the rate controller, a acceleration and deceleration profile were made for smoother motion of the prosthesis arm using linear filter. The scheme of CDC(classified direction contoller) is shown in fig.2. The max-min method was used for the Fuzzy logic inference method.

RESULTS

In this paper, we have presented a new approach to the EMG signal analysis in decision space that decreased decision errors using fuzzy reasoning logic in the aspects of the Euclidean distance measure. Comparing linear interpolation with the suggested approach, we found that the continuity of decision space is closer to real movement in the presented method. Especially, at the time of decomposing, we didn't have to make an effort to calculate inverse Jacobian by introducinig RMRC (Resolved Motion Rate Control).

DISCUSSION

The fuzzy reasoning logic and decomposition in determination space of EMG pattern classification for a prosthesis arm con trol was useful to reflect the characteristic of EMG which would suggest a way to control multidegree freedom of a prosthesis arm. If we could place the electrode near the neuron in a muscle, it would a give a more proper signal which has less artifact and could be applied more rapidly for a reliable EMG signal classification. Since the primitive and combined motions which were used for the experiment were so restricted, we are considering the experiments for more detailed movement and combined motions of more than three. A nonlinear part of decomposition in a mapping from decision space to control space could be resolved by enhancing fuzzy rules.

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VIBROTACTILE FEEDBACK FOR DEXTROUS TELEOPERATION

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ABSTRACT

The limitations of providing vibrotactile information in a teleoperated robotic system were investigated. Up to four channels of vibrotactile feedback were given to a human operator to relay force information from a dextrous robotic hand. Significant advantage was seen when the operator was provided one or two channels of feedback.

BACKGROUND

In man/machine interfaces, such as in telerobotics, an important task is relaying information to the operator. Vibrotactile feedback has been suggested for such use, since it does not interfere with the other senses (1). Extensive studies have been performed using feedback for simple robotic manipulators, but not with high degree-of-freedom (DOF) manipulators (2). Our research investigates whether multiple channels of vibrotactile feedback can be used to control a high DOF robotic manipulator.

Tactile feedback has been shown to be useful as a sensory substitution aid (3). The effects of learning and coding for one and two channels of tactile feedback were studied (1). More feedback channels increases the amount of information available, but also increases the human tracking error.

Visual feedback for present day manipulators may need to be augmented. Human limitations in processing the information from multiple sources and multiple parameters need to be investigated. In this study the effects of using up to four channels of vibrotactile feedback were tested in a high DOF robotic hand.

RESEARCH QUESTIONS

1. What is the advantage gained from providing force information through vibrotactile feedback?

2. What are the effects of increasing the number of channels of feedback information?

METHOD

A NASA/Goddard dextrous robotic hand with sixteen DOF was used. Force sensors were placed on four of the finger tips of the hand. Each sensor relayed force information using vibrotactile stimulators placed on the fingertips of the human operator. A VPL DataGlove (VPL Inc., CA) read the finger angles of the operator; these values were used to control the robotic hand.

The experiment was then performed as follows: the subject was told to use the fingers of the robotic hand to press a push-button until a LED light turned on, which occurred at a preset target force. The test was performed using one, then two, then three, and finally four fingers simultaneously. The number of channels were defined as the number of fingers used in each test. The test was repeated five times for each finger, performed first with no feedback, and then with vibrotactile feedback. Five subjects participated in the experiments (2 male, 3 female, ages 18 ± 2 years) resulting in twenty-five tests. One trial was performed daily for four days. The error for each test was calculated:

$$error = 100\% \frac{F_s - F_t}{F_t} \qquad (1)$$

where Fs is the force recorded from the subject, and F_t is the target force. The root mean squared error (RMSE) for each trial was then calculated:

$$\mathrm{RMSE} = \frac{1}{25}\sum_{t=1}^{25}\sqrt{error^2} \qquad (2)$$

where t is the test number. The RMSE was calculated separately for each channel. The relative advantage of adding vibrotactile feedback (ADV) was then calculated:

$$\mathrm{ADV} = \frac{\mathrm{RMSE}_{vf} - \mathrm{RMSE}_{nf}}{\mathrm{RMSE}_{nf}} \qquad (3)$$

where RMSEvf is the RMSE while using vibrotactile feedback, and RMSEnf is the RMSEwhile using no feedback. The ADV was calculated for each channel, and averaged over the four trials.

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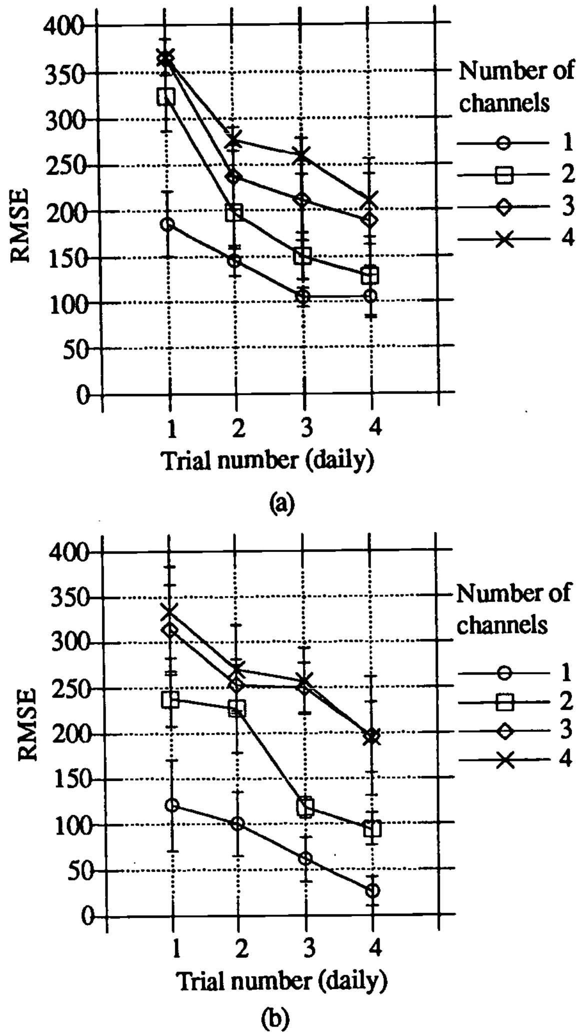

Figure 1: RMSE (root-mean-squared-error) over four daily trials (a) With no feedback (b) With vibrotactile feedback.

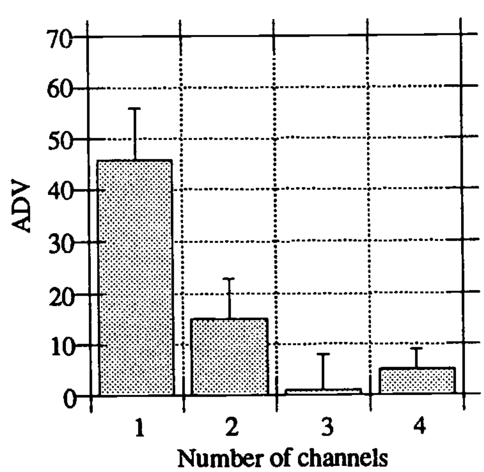

Figure 2: Average ADV (advantage of using vibrotactile feedback over no feedback) in percent per number of channels used.

RESULTS

Figure 1 shows the RMSE per trial results from the experiment. Lower RMSE indicates an improved achievement of target force levels. The RMSE increases significantly as the number of channels used increases. However the RMSE decreases significantly per trial. Averaged over the channels, the RMSE decreased per trial by an average of 12% with no feedback, and 11% with vibrotactile feedback.

Figure 2 shows the ADV from using vibrotactile feedback. Higher ADV indicates an improvement in RMSE from using vibrotactile feedback. The ADV is shown from using one to four channels. The results are averaged over the four trials from all subjects. One and two channels of vibrotactile feedback show a significant ADV of 46% and 15% respectively. The results from three and four channels of vibrotactile feedback were not statistically different from no feedback.

DISCUSSION

The results show that increasing the number of feedback channels increased the RMSE. This occurred for tests both with and without vibrotactile feedback. This probably was due to the difficulty in manipulating several fingers simultaneously.

The RMSE also decreased per trial. This was expected for tests with no feedback, since the subjects had no previous familiarity with the robotic hand. The RMSE were also consistently lower per trial with vibrotactile feedback. This indicates that learning of vibrotactile feedback may also be occurring during the experiment.

The results from ADV calculations showed an advantage in using vibrotactile feedback. The data show that in every case, the use of vibrotactile feedback lowered the RMSE and produced a positive ADV. However, the differences were significant only when one or two channels of feedback were used. When three or four channels were used, the results were not statistically different from when no feedback was used.

Our results are consistent with earlier findings. Szeto reported that for tactile tracking experiments, the errors decreased per trial, with the largest decrease resulting after the first trial. He also showed that the tracking error increased as the number of channels increased (4).

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CONCLUSION

There is an upper bound on the number of vibrotactile feedback channels that can be used for teleoperation. Our preliminary studies indicate a maximum of two channels. Using more than two channels of feedback did not show any significant improvement in performance over trials with no feedback. Further studies are required to investigate the benifits of multiple channels of vibrotactile feedback.

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FEEDING THE PHYSICALLY CHALLENGED USING COOPERATIVE ROBOTS

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ABSTRACT

This paper describes a robotic system for feeding the physically challenged. A prototype intelligent robotic aid system called the ISAC (Intelligent Soft Arm Control) is being developed for the service sector. Recently we have begun to integrate a HERO 2000 mobile robot with ISAC to extend the system capabilities.

BACKGROUND

Rehabilitation engineering is dedicated to providing life-enhancing equipment for the disabled. Many rehabilitation robots have been developed. For example, the MANUS wheelchair-borne manipulator [1] was developed for persons with severe disabilities of all four limbs. This manipulator is controlled by the user through teleoperation. Teleoperated manipulators are those whose joints motions are in direct, real-time control by the user.

Teleoperation has traditionally been the way by which such systems perform desired actions. However, users tend to find teleoperation very tiring and prefer to substitute them with high level commands [2]. To achieve this, the system must provide high level commands which are executed autonomously by the robot with the help of various sensors.

A prototype robotic aid system called ISAC was developed for feeding the disabled [3]. To insure ease of use, safety, and flexibility of the system, we have integrated several sensors such as vision, voice, touch and ultrasonic ranging. The user interacts with the ISAC in natural language-like (high level) commands such as *feed me soup*. Recently, a HERO 2000 mobile robot has been integrated with ISAC to extend its capabilities.

The architecture of the ISAC system is shown in Figure 1. There are two main hardware modules in our system: (1) a robot arm called the Soft Arm and (2) a mobile robot called HERO. The Soft Arm is a pneumatically-actuated, flexible manipulator. The arm is light and suitable for operation around humans. The HERO 2000 is a mobile robot with a 5 DOF arm.

*On leave from Minolta Camera Co., Ltd., Osaka Japan.

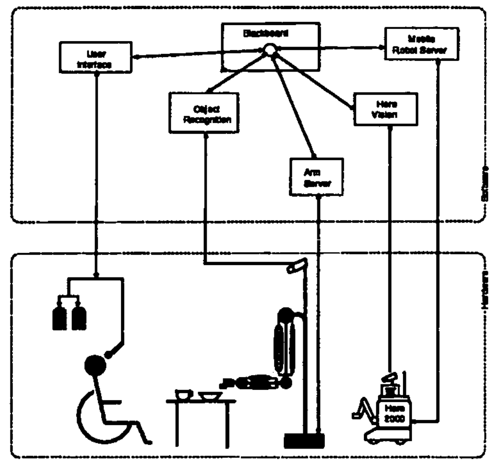

Fig. 1. Hardware and Software Environment

RESEARCH QUESTIONS

The initial goal for the cooperative ISAC-HERO system is to locate a soda can from an unknown location and bring it the user. To accomplish this goal, the following problems need to be examined:

1. Scanning a cluttered environment for the soda can. This involves segmentation of the can from the background.
2. Navigation of HERO to the soda can, using an estimation of the relative position between HERO and the can.
3. ISAC-HERO soda can exchange, requiring communication and cooperation between the two robots.

In dealing with these tasks the following assumptions were made:

1. The size and color of the soda can is known.
2. The soda can stands upright at approximately the same height as the camera.
3. The environment is dominated by inconspicuous monotone color.
4. Lighting conditions are reasonably constant over the scene and are known.

These assumptions simplify the problem, thus speeding up the process. The methods used to address these issues are described in the following section.

METHOD

Environmental Scanning

Since the location of the soda can is initially unknown, the camera scans the environment as HERO rotates around its base until it detects a can. The soda can is detected using a color-based segmentation algorithm. The data flow of this algorithm is shown in Figure 2.

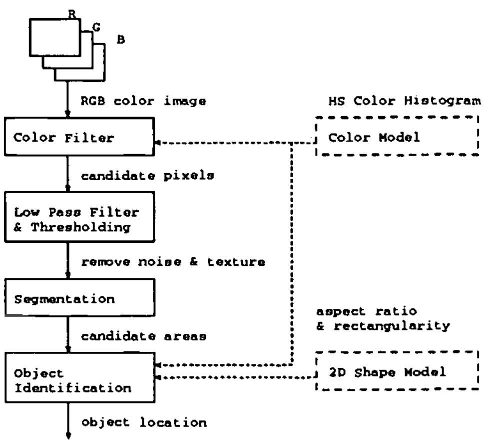

Fig. 2. Object Segmentation Module

In a cluttered environment, like an office or a living room, it is hard to detect an object by geometrical properties. However, if *a priori* knowledge of the object's color is available, it reduces the search space. This is especially true in our application since soda cans are intentionally designed to be salient.

The color model of the object is represented in the HSI (Hue, Saturation and Intensity) color space. The object's color model is stored in the form of a histogram in the color space [4].

Sensitivity to lighting conditions is the main drawback of using color for object identification (color constancy problem) [5]. Color constancy is simply implemented in our system by eliminating the intensity component from the color model. This simplification is valid if two conditions are satisfied: First, the secondary reflections are negligible, and second, the object is subjected to the same type of light source as one used while constructing the model. Both of these conditions are satisfied in our environment.

Color is the primary property for segmenting the can. After segmentation, the 2D geometrical property of each region is analyzed as a secondary property. The object identification module identifies the can by fitting a rectangle to each segmented region and choosing the largest region.

Navigation

An autonomous robot should be able to navigate in an unknown environment. The robot must have the capability of "sensing" the environment. There are various sensors for mobile robots including lasers, ultrasonic sensors, and visual sensors.

In our system, HERO relies on a vision sensor for navigation; namely a color CCD camera. The vision system locates the soda can in the image, and estimates the distance and steering angle of HERO relative to the can.

The objective of navigation is to guide HERO towards the can. Therefore, the navigation module must continuously estimate the location of the can in terms of distance and steering angle. Distance is estimated by triangulation using the focal length, *a priori* knowledge of the size of soda cans, and the size of the projected image of the can. The steering angle is estimated similarly by triangulation using the focal length of the camera and the centroid of the can on the image plane. These estimations are inaccurate when the can is located at a far distance or at the periphery of the image. Thus, HERO compensates its position by centering the can in the images as it moves closer.

ISAC-HERO Soda Can Exchange

One of the most technically demanding tasks in any multi-robot system is the movement coordination among robots. In our case, HERO must hand a soda can to the Soft Arm in an adaptive manner using sensor feedback. This feedback is provided by a camera mounted on ISAC, once HERO enters its field of view. Since the Soft Arm can not grasp a soda can directly, HERO must insert the can into a cup held by the Soft Arm. ISAC steers HERO to the cup by tracking the top of the soda can. The top of can is easily segmented by thresholding due to its brightness. The flexibility inherent the Soft Arm allows the can to be inserted into the cup without need for force feedback. ISAC takes the soda to the user using a face tracking module that determines the 3D position of the user's face in real time.

RESULTS

The ISAC-HERO system has successfully addressed the various issues raised by this application. This section discusses these results.

The result of segmentation during environmental scanning is shown in Figure 3. We were able to successfully locate a red can from the image. The whole process, including image acquisition, takes

Fig. 3. Segmentation of a Soda Can

approximately 5 seconds. Notice that the other can whose main color is green is not detected.

The estimation of distance and steering angle has been found to be accurate enough to navigate HERO to the soda can. Obstacle detection and avoidance has not been implemented yet.

ISAC's vision system tracks the top of the soda can in HERO's gripper as shown in Figure 4. The white circle in the figure shows the segmented region used for tracking. The centroid of this region is used to determine the position of the can in robot coordinates. This information allows ISAC to steer HERO to the exchange point.

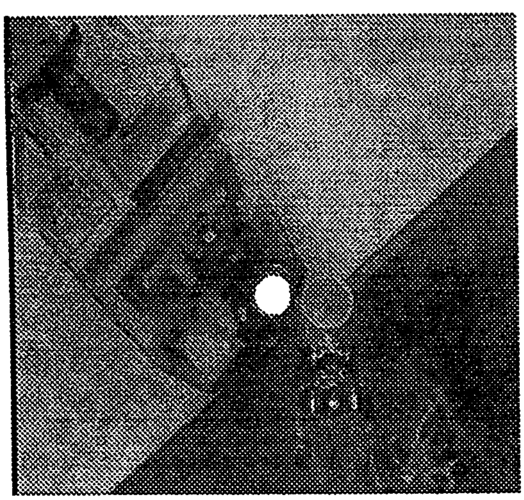

Fig. 4. Location of the Soda Can by ISAC's Vision System

DISCUSSION

In this paper, an experimental collaborative robotic aid system for feeding the physically challenged was described. A robotic aid system with a static robotic arm was combined with a mobile robot to extend the capabilities of the existing system.

Two robust vision algorithms were developed to direct the mobile robot to the soda can. The first algorithm, based on color, locates the soda can in the scene. The second algorithm, based on geometric properties, estimates the distance between the can and the mobile robot and determines the steering angle. Soda can exchange between two robots has been implemented using a predetermined exchange point.

Much work remains to be done to make this collaborative system truly adaptive. Work on segmentation using multiple colors is in progress. Sonar sensors on HERO will be used for obstacle detection. Finally, clinical evaluation of this system is yet to be accomplished.

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A ROBUST, SELF-DIAGNOSING SENSING METHODOLOGY FOR APPLICATION TO SMART WHEELCHAIRS

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ABSTRACT

The author proposes a robust, redundant, dynamic, self-diagnosing sensing methodology for application on smart wheelchairs which detects and compensates for hidden failures of single sensors and sensor idiosyncrasies. The arrangement consists of a network of intelligent sensor clusters, each composed of multiple sensors.

BACKGROUND

A number of researchers have proposed the development of a "smart" wheelchair (1, 2, 3). The target population of users typically consists of those people who need powered mobility but whose physical disabilities prevent them from operating a typical power wheelchair. The advantages of such a system are numerous, including increased independence and self-esteem of the user, reduction of the user's cognitive workload, and facilitation of the user's incorporation into the world at-large (2).

A primary requirement to be considered in the development of any such system must be safety (4). This includes both the safety of the user and of the environment. An important observation must be made at this point: a smart wheelchair system involves shared control. As such, the system is empowered to take action on behalf of the user at the user's request, but not necessarily under the user's direct control. This arrangement introduces the possibility of user or bystander injury caused by a "bad" choice of control output on the part of the system (5). The ramifications of this with respect to who is to blame for such an injury could keep the courts busy for years. Clearly, it behooves anyone intending to implement a smart wheelchair system to be as thorough as possible to make the system as safe as practical.

Clearly then, there are two important goals to be achieved in the realization of a smart wheelchair system: first, facilitation the user's mobility, and second, safe operation. To achieve these goals, the system must have a means of understanding the environment so that it can interact with it appropriately. This implies a high-quality, robust sensory system.

THE PROBLEM

The sensor system is the link between the smart wheelchair and the external world. Everything that the smart wheel chair knows about the world must come to it through this system. As such, a failure or shortcoming in this system could have dire consequences. One could envision a number of possible modes of failure, including total, partial, and hidden. Shortcomings include sensor idiosyncrasies.

Total failure of the sensor system is rather easy to detect and respond to. One has no choice but to halt operations and signal for external help. One would expect this situation to be rare if sufficient redundancy is designed into the system at the outset. The handling of partial failures is also relatively straightforward. In this case, one would rely on the remaining sensors to continue operation, although at a reduced level of confidence and performance. It is rather more difficult to detect and compensate for hidden failures and sensor idiosyncrasies.

A hidden failure is one in which a sensor ceases to interact with the environment, yet continues to return measurement values. The detection of this type of failure requires multiple, independent sources of data for comparison purposes. If on comparison of the values, one finds a discrepancy, it can be assumed that at least one sensor is faulty. The determination of which sensor is most likely to be at fault can then be done statistically, in which case the more sensors the better (but at least three). After identification of the offending sensor, it can be marked as bad and taken off-line.

Sensor idiosyncrasies are limitations imposed either by the nature of the particular sensor's mode of interaction with the environment or by its inherent physical characteristics. For example, sonar sensors have difficulty detecting objects which have low acoustic reflectivity. One way to compensate for sensor idiosyncrasies is to employ sensors of different types in complimentary pairs. In this case, a disagreement between sensor pairs would alert the system to reexamine its interpretation of the meaning of the data being returned and perhaps employ a backup system of yet another sensor type.

A SOLUTION

In the following, the author proposes a robust, redundant, dynamic, self-diagnosing sensing methodology for detecting and compensating for hidden failures of single sensors and sensor idiosyncrasies, based on a "2+2" arrangement. This arrangement consists of a number of intelligent sensor clusters, each composed of four sensors, two each of two different types, coupled with a local processing unit, all grouped into a larger network (Figure 1).

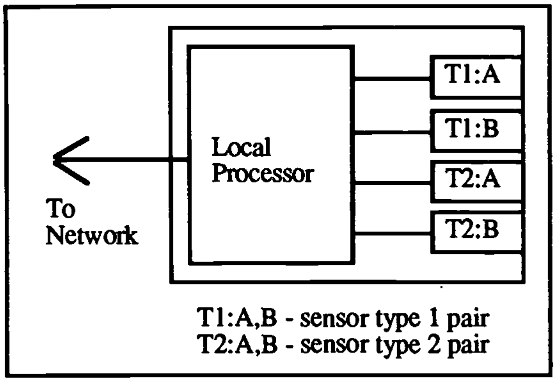

Fig. 1: Intelligent Sensor Cluster

In the following discussion, it is assumed that each intelligent sensor cluster operates its sensors in an approximately synchronous, spatially coherent manner. That is to say, each "reading" consists of essentially simultaneous measurement by all sensors in the same approximate spatial direction (although slight time allowances might have to be made in the case of certain sensors to prevent mutual interference).

In operation, each intelligent sensor cluster would track the values returned by its sensors, looking for both near-term and long-term inconsistencies. Near-term inconsistencies would be such things as disagreement between values returned by sensors during one reading. Long-term inconsistencies would include such things as the number and types of sensor disagreements recorded within the last N readings. This information would then be used to develop a statistical profile of the intelligent sensor cluster's performance for diagnostic purposes and to assign a confidence value to its output. In particular, each intelligent sensor cluster would maintain the following "agreement matrix," where agreement is suitably defined (Figure 2):

	T1:A	T1:B	T2:A	T2:B
T1:A	NA	A/D	A/D	A/D
T1:B	A/D	NA	A/D	A/D
T2:A	A/D	A/D	NA	A/D
T2:B	A/D	A/D	A/D	NA

A/D: A = agree, D = Disagree
NA = not applicable

Fig. 2: Agreement Matrix

Consider the case of the hidden failure of a single sensor. In this case, assuming no coincidental agreement, one row and one column of the agreement matrix will contain all 'D's. Based on this, one can tentatively mark this sensor as faulty and adjust the

intelligent sensor cluster's confidence value appropriately. In general, coincidental agreement will be detected over the long-term as the system moves around. A hidden failure of more than one sensor would typically require the intelligent sensor cluster's confidence value to be reduced to zero.

Now consider the case of measurement inaccuracies introduced by sensor idiosyncrasies. In this case, one would expect each like pair of sensors to produce measurements which agree each other, but not necessarily agree with the measurements produced by the other pair of sensors. For example consider the case of an intelligent sensor cluster composed of pair of sonar range sensors and a pair of laser range sensors confronted with a glass door (Figure 3). The pair of sonar sensors would 'see' the door, but the pair of laser sensors might not. In fact, they might sense something beyond the door. In such a case, one would take the conservative approach and believe the smaller measurement. Trusting to a single type of sensor in many cases can thus lead to disaster. By employing different types of sensors in this manner, one can possibly avoid being misled into believing things to be all clear when in fact they are not.

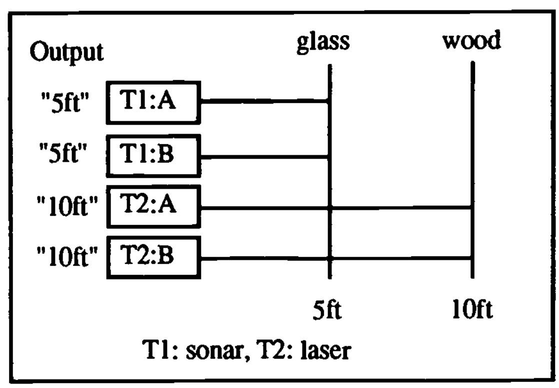

Fig. 3: Sensor idiosyncracy

The exact criteria for determining whether two sensors "agree" would depend upon the degree of confidence one would want to achieve in the intelligent sensor cluster's output. The narrower the range of variance allowed between two measurements considered equal, the higher one's confidence in the intelligent sensor cluster when measurements do agree. Corresponding to this, the narrower the range of variance allowed between two measurements considered equal, the more likely a set of measurements are to be in disagreement. This is a trade-off that requires empirical adjustment.

At the level of the entire network of sensors, one could employ a central processor to gather information to assemble it into a coherent view of the smart wheelchair's environment. This unit

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could selectively ignore the output of those intelligent sensor cluster's whose confidence values have fallen below a specified level. It would also be able to provide diagnostic information as to which intelligent sensor cluster units are faulty, along with hints as to what the actual fault might be.

IMPLEMENTATION

The author is presently conducting research into robotics applications for individuals with motor disabilities. Currently, a project is underway to implement this system for performance analysis on a modified Denning robot. After this, the author intends to implement this on a smart wheel chair.

DISCUSSION

The advantages of this strategy are as follows. First, it allows pair-wise checks between like sensors to detect hidden failures. Second, it helps prevent being blinded by a particular sensors idiosyncrasies. Last, it insures an assured level of safety by providing fault-tolerance, redundancy, and self diagnostics.

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THE ASSISTIVE RESEARCH AND TECHNOLOGY WHEELCHAIR MOUNTED ROBOTIC ARM: PROTOTYPE REVIEW

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Abstract

A prototype wheelchair mounted robotic system has been developed by Assistive Research and Technology Inc. (ART). Wheelchair mounted robotic systems hold a great potential for helping individuals with disabilities. Unfortunately, this potential has yet to be reached. There are a number of designs and functional attributes that have to be met if a particular robotic system is to be considered useful and functional. Along with a brief description of the ART arm, essential design characteristics of wheelchair mounted robotic manipulators will be discussed as well as how the ART robotic arm addresses these characteristics.

Introduction

The Assistive Research and Technology Inc. (ART) robotic manipulator is a prototype arm that is intended to be mounted on an electric wheelchair. There are many functional attributes to consider when designing a wheelchair mounted robotic manipulator. These attributes often differ from characteristics desirable in traditional robotic systems. Assistive Research and Technology lent their prototype arm to ASEL for basic testing and review. The Assessment Laboratory at the Rehabilitation Engineering Research Center in Rehabilitation Robotics (RERC) at ASEL evaluates prototype robotic devices such as the ART arm. Part of reviewing the ART robotic arm involved evaluating how well the arm addressed some of these key design considerations.

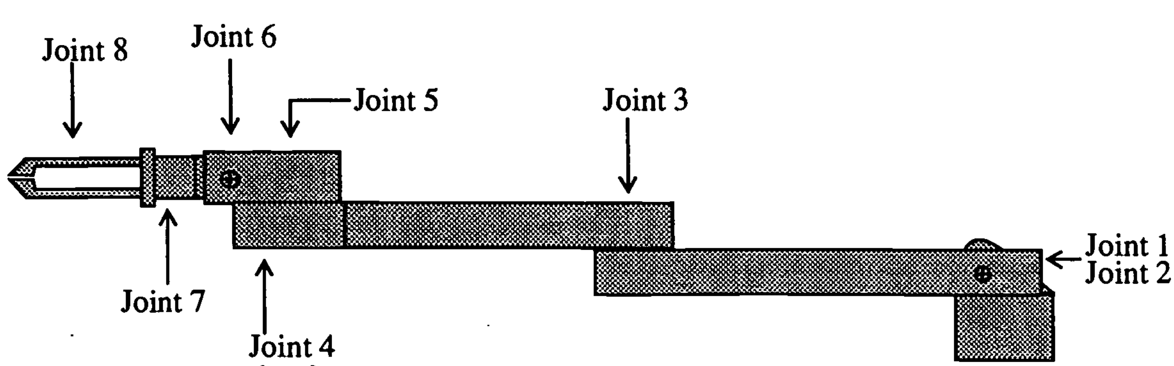
Statement of the Problem

The main focus of rehabilitation robotics is bringing robotic technology to the elderly and individuals with disabilities in order to enable independence in their everyday lives. Wheelchair mounted robotic manipulators, such as the MANUS and the Papworth Inventaid arm, are example of how robotics are being applied to meet the needs of individuals with physical disabilities [5]. Compared to other robotic systems, wheelchair mounted systems offer some important advantages. For example, unlike stationary robotic systems, they can be operated and transported in an unstructured environment. Secondly, fully autonomous robots are typically more expensive and more complex than wheelchair mounted robots [1]. There are many desirable and essential attributes that should be included in the design of a wheelchair mounted robotic manipulator. These design attributes can directly affect a robotic system's potential success in aiding an individuals with disabilities.

Rationale

A number of wheelchair mounted robotic systems have been developed in order to assist the needs of individuals with disabilities. Unfortunately, none of these systems has been widely accepted as either clinically or vocationally acceptable [4]. The reason for this is that none of the commercially available systems have, at a reasonable cost, successfully met all design criteria of a functionally useful wheelchair mounted robotic manipulator. Although there have been few successes in

Figure 1: Joint layout of the arm



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the past, wheelchair mounted robotic arms, like the ART arm, have to be researched and explored in order to realize the potential these types of robotic systems hold for helping individuals with disabilities.

Design

The ART arm is a joint controlled robotic arm that offers seven degrees of freedom plus a gripper (see Figure 1). When folded away, the arm is extremely compact (22.25" x 11.0" x 5.5"). The arm and mounting system weighs approximately 60 lbs. When the arm is extended, it offers up to 58" of reach. The joints of the arm are all driven by DC motors which are powered by the batteries of the wheelchair. Unlike the MANUS, which has all its motors placed in its base, [3] the ART arm has all of it motors mounted at the joint which the motor drives. The ART arm presently offers no computer interface or integrated control.

Evaluation

Safety

Unlike many industrial robotic systems, wheelchair mounted robotic arms are intended to be used in close proximity to humans. The safety of both the user and those in the user's environment is of prime importance. Compliance, or "softness", is one of the characteristics that adds to the safety of rehabilitation or assistive robots [2]. The ART arm uses adjustable slip clutches to implement compliance in 5 of its 8 joints. This allows the compliance to be changed and adjusted for different tasks and users. The other three joints are set with a fixed amount of compliance.

Another aspect of safety deals with limiting the range of motion of the arm. There needs to be some mechanism in a wheelchair mounted robotic arm system that prevents the arm from being placed in potentially dangerous positions. The ART prototype does not yet have any such mechanism. Currently, the ART arm can be manipulated into virtually any position, some of which are unnecessary and even potentially dangerous.

Feedback

Feedback from the robotic arm aides the user in accomplishing tasks. Feedback can provide the user with information about the robotic system as well as the surrounding environment. In the MANUS, for example, the user is alerted to errors in the system, range of motion limits, and mode changes by a combination of auditory and visual feedback mechanisms. Other robotic systems, particularly industrial systems, have various types of sensors that provide additional types of feedback. The only feedback currently provided by the ART robotic arm is the visual feedback offered by watching the robot in motion.

Wheelchair Profile

One of the constraints placed on the design of a wheelchair mounted robotic arm is that it should not increase the width of the wheelchair by an amount that interferes with the wheelchair's movement through doors [2]. The ART robotic arm addresses this problem by mounting the arm behind the wheelchair. The prototype mounting system was designed to fit a Fortress electric wheelchair and the mount places the robotic arm approximately 7 inches behind the top of the seat of the wheelchair. When folded up, the entire arm sits behind the wheelchair. Neither the mounting system nor the robotic arm increases the overall width of the Fortress wheelchair. Mounting the ART robotic arm behind the chair does, however, have some potential drawbacks. While the ART arm is either folding in or folding out. there is a time in which the entire arm is out of the user's field of view.

Functionality

Lifting capacities were determined for two joints that counter gravity, the shoulder (Joint 2) joint and the wrist pitch (Joint 6) joint. (see Figure 1). In both cases, a rack of weights was lifted by the arm using just the joint being tested. Lifting capacity of a joint was determined by the amount of weight the arm was trying to lift when either a joint slipped or a motor stalled.

TABLE 1.

Joint being tested	Weight successfully lifted
shoulder (Joint 2)	4.9 kg
gripper pitch (Joint 6)	1.7 kg

A consumer researcher with a C3/C4 spinal cord injury used the ART arm to perform simple tasks to test the arm's functionality. These tasks ranged from manipulating blocks to pouring water from bottles. The tasks were devised so that all the degrees of freedom of the robot were used. The consumer researcher was able to successfully complete the assigned tasks with very little familiarity with the arm.

User Interface

Regardless of how advanced a rehabilitation robotic system is, it will be under utilized if it has a poor user interface. Good user interfaces are characterized by their transparency [4]. The ART arm is currently controlled by a 16 switch control box. The switches are arranged in pairs, where each pair controls a single joint of the arm. Each switch moves a joint in one particular direction. The control box also includes a switch that allows the user to toggle between slow and fast motor speeds. This control box, though fully functional, was never intended as a final, optimal interface. It was provided with the ART arm merely as a control unit during the testing stages.

Discussion

Developing an accepted and functionally useful wheelchair mounted robotic system takes more than just satisfying the design characteristics mentioned in this paper. There are numerous other factors that have to be considered as well. Will the robotic system perform significantly better than the systems, mechanical and human, the user presently has in place? Will the robotic system be accepted by society? Other issues that have to be considered include matters of aesthetics, noise generated by the system, cost and availability of the system, cognitive load required to operate the system, and the overall reliability of the system.

The ART robotic arm successfully addresses a number of the design characteristics crucial to designing a wheelchair mounted robotic system. Mounting the arm behind the wheelchair, for example, helps to reduce the overall width of the wheelchair and robotic system. Before marketing the ART robotic arm, however, it needs to meet all the mentioned design criteria. Limit switches and sensors should be added to increase the safety of the arm. A simple and functional user interface has to be included with the system. Since users' capabilities will differ, both cognitive and physically, an optimal solution would be to provide a variety of user interfaces for the ART arm. Mounting the motors along the length of the arm simplifies the drive mechanisms, but causes a significant increase in the moment of the arm when fully extended. This causes considerable bounce in the arm when using either the number 1, 2, or 3 joints. Eliminating the bounce in the arm would ease the overall use of the arm.

Wheelchair mounted rehabilitation robotic systems are complex systems to develop. Because of their advantages, such as mobility and size, these systems do hold great potential for aiding individuals with disabilities in their daily lives. The ART robotic arm, the first device reviewed by the Assessment Laboratory of the RERC, successfully meets some of the design criteria mentioned in this paper. The Assessment Laboratory will continue to provide the service of evaluating prototype robotic devices throughout the duration of the RERC in Rehabilitation Robotics. With ingenuity and critical evaluation these prototypes may become marketable products, improving independence for individuals with disabilities through technology.

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The Use of the Soft Arm for Rehabilitation and Prosthetics

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Abstract

A review of robotic devices used for rehabilitation and as aids to the disabled is presented. One special type of device called the Soft Arm is discussed and its advantages are listed. A new direction for research is proposed. The Soft Arm's Rubbertuator technology could be used as the basis for a new type of lightweight, inexpensive prosthetic limb or rehabilitation aid that would take the form of a replacement limb or an active brace for the patients limbs.

Introduction

Service robots are designed to operate in an unstructured environment to work with or assist humans. Ease of use, economic considerations and safety are most important factors in service robots. With continuous increase in health care cost and the increase of the elderly population, the role of robots in aiding the disabled and elderly is becoming very important. Several projects have been initiated in the United States, the European Community and Japan to develop robotic aid systems that can help integration of the elderly or the disabled into society [1, 2].

In this paper, a brief background on the use of service robots for the rehabilitation will be presented. Next, the Soft Arm robot and it use in the ISAC (Intelligent Soft Arm Control) being developed at the Intelligent Robotics Laboratory at Vanderbilt University will be discussed. The last section will discuss the use of the Soft Arm and its Parallel Controller as an intelligent prosthetic.

Background

This section will present some robotic aid systems that performs different rehabilitative tasks.

DeVAR (Desktop Vocational Assistant Robot) is developed at Stanford University under the Department of Veterans Affairs. It uses a PUMA-260 robot with modified Otto-Bock Greifer prosthetic hand as a gripper. The arm is inverted and runs on a track above the working area. It can be used to handle paper and floppy disks, picking up and using the telephone and retrieval of medication. A voice recognition system is used to command the arm [3, 4, 5].

RAID (Robot for Assisting the Integration of the Disabled) is a system developed under the European Community TIDE program that uses a modified RTX robot in the SCARA-configuration. It is intended for office use. It consists of a PC, a fax, a telephone, a printer and a the robot manipulator. It is operated from a joy stick mounted on the user's wheelchair [6, 1].

In Japan, a Meal Assistance Robot System is developed at SECOM's Intelligent Systems Laboratory. This system uses a specially designed arm that is simple, light and small. The hand has a spoon and spatula which increase the ability to grasp and serve. The user commands the arm using an optical pointer mounted on his or her head and a sensor panel [7].

MANUS is an electrically powered arm with its motors and motor controllers mounted in the base of the arm [6]. Individually selectable controls and reconfigurable microcomputer-assisted procedures are used to control both gripper and the wheelchair [8]. It is intended to operate in an unstructured environment of which it has little or no prior knowledge. Thus much emphasis is placed on the interactive procedures in which the user directly controls the gripper.

WALKY is a mobile robot system which will be used to assist work-injured people at chemical laboratories. It was developed at CERTEC (Center of Rehabilitation Engineering) at the Lund University, Lund, Sweden [9]. The main goal of this project is to get these people back to their jobs earlier. It consists of a Scorbot ER VII robot mounted on a Labmate mobile base. The user commands the mobile robot by pointing at an AutoCAD drawing. WALKY can navigate using ultrasonic sensors and a simple obstacle avoidance algorithm.

Kawamura *et al.* [10] presents a classification of service robots for rehabilitation based on the system hardware configuration.

All the above systems uses either a table-mounted, a wheelchair-mounted or a mobile robot. Most of these systems use an industrial robotic arm which may pose hazard to the user in case of failure of malfunction.

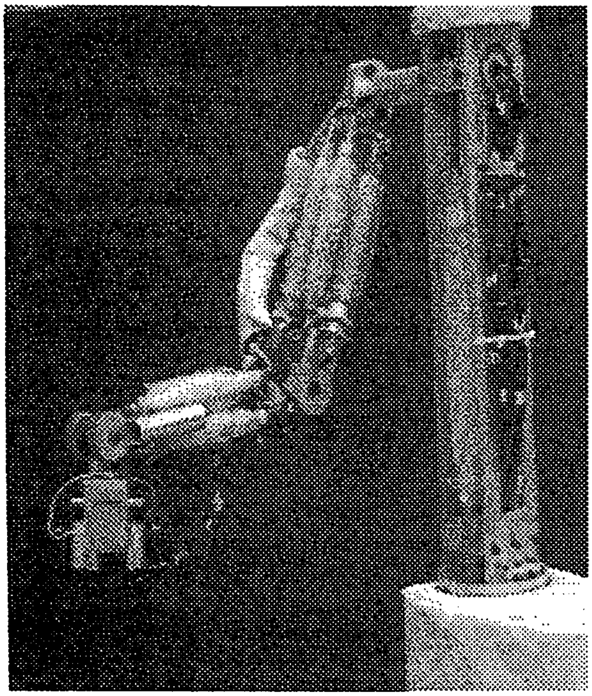

Fig. 1. Picture of the current Soft Arm showing Rubbertuators

The Soft Arm and the ISAC System

Currently we use the Soft Arm as part of the ISAC system. ISAC is an integrated system that feeds a patient and can be directed by voice command. Unlike most industrial robots, the Soft Arm has several intrinsic features that make it uniquely suited for the service sector. First the joints are naturally compliant and the Soft Arm has a mechanical structure similar to that of the human arm as in Figure 1

We have developed a controller for the Soft Arm called the Parallel Controller, which uses a network of processing nodes to control the joints of the Soft Arm in parallel. The primary advantages of the Parallel Controller are modularity, robustness and fault-tolerance [11]. The controller can tolerate some degree of failure while gracefully degrading performance because the duties of one node can be assumed by another processing node during operation. This type of modularity also allows the controller to be easily extended to handle mechanisms with many degrees of freedom.

Intelligent Prosthetics using the Soft Arm

The Soft Arm possesses several advantages for future use as an intelligent prosthesis or rehabilitation device. Rubbertuators are much lighter and smaller than motors or hydraulic actuators of the same strength and are flexible much like natural muscles [12]. The rubbertuators use air instead of messy fluids like hydraulics and require no bleeding or draining of lines. Additionally, rubbertuators provide force feedback in the form of the air pressure inside them, whereas motors and hydraulics generally require more expensive strain gauges to implement force feedback. Rubbertuators work like muscles in opposing pairs and under clothing would look very natural, like human muscle contraction. Another important advantage of the Rubbertuator in this application is that the rubbertuator can be readily scaled to approximate any muscle from large thigh-sized muscles to small wrist-sized muscles, with corresponding scaling of strength. Years of experience and research on control of rubbertuator powered manipulators could immediately be brought to bear to produce an integrated controller for the rubbertuator based prosthetic. The modular nature of the parallel controller and miniaturization of control electronics would allow the Parallel Controller to be integrated within the structure of the arm itself. Finally, the device could be powered by a small compressor pack approximately the size of a fanny-pack that would provide hours of use.

Given these advantages, it would be worthwhile to develop rubbertuator based devices as prosthetics and rehabilitation aids. Two classes of device seem feasible based directly on the technology of the Soft Arm robot:

- Rehabilitation
  A device would be designed that attached to a patients arm and acted to assist the patients motions. The amount of assist could be varied and controlled by small microcontrollers in the device. This device could be a form of physical therapy to help patients recover from injuries, or a permanent device that offests loss of strength due to muscular atrophy.
- Prosthesis
  A device very similar to the Soft Arm could be use as a prosthetic arm controlled by microcontrollers within the arm. The light weight of rubbertuators would allow a device to have a weight close to the natural arm weight. In this capacity Rubbertuator-based devices could provide great flexibility in a prosthetic device.

Conclusions

Given the advantages of rubbertuator technology and the progress in using the Soft Arm as part of the ISAC system, we suggest that device could be developed further to serve as an aid in rehabilitation or a prosthetic device for the disabled. It is hoped that this technology could be developed to provide lower cost and better performance prosthetic devices in the future.

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MOTION SIMULATION FOR AN IMPROVED ORTHOSIS

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ABSTRACT

The objective of this research was to determine the optimal configuration of a powered upper-limb orthosis. The criterion was to minimize the orthosis complexity while maintaining the ability to perform specific tasks. Three stages of research were involved in achieving this objective: 1) the priority tasks were determined by interviewing potential users, 2) the paths, orientations and joint angles of able-bodied subjects performing these tasks were determined using a video tracking system, and 3) the ability of alternative orthosis configurations to perform the tasks were evaluated using a developed computer simulation.

The research results indicate that task functionality is overly compromised for orthosis configurations with less than five degrees of freedom plus prehension. Two alternative configurations with five powered and two fixed degrees of freedom are recommended. A prototype orthosis is currently being developed using the results of this research.

BACKGROUND AND OBJECTIVE

A powered upper-limb orthosis is an exoskeleton worn on one arm by a person with severe arm muscle weakness in order to perform tasks such as eating, reaching for objects or washing the face. Previous powered orthoses have generally either been too complex or lacked sufficient function [1-7]. The majority reproduced all but one of the seven degrees of freedom in the human arm [1,2,4,7], while the simpler designs selected the degrees of freedom based on joint priority. Although previous researchers had evaluated alternative prosthesis designs, the task requirements differed from those in this research [8,9]. Thus, while there is a clear need for compromise between simplicity and functionality in an orthosis, the optimal compromise was unknown.

The goal of this research was to determine the optimal selection of orthosis degrees of freedom in order to produce a more user-acceptable orthosis. Given this goal, the set of priority tasks had to originate with potential users. Although surveys had been conducted previously with potential and active users of rehabilitative robots [10-15], additional interviews were required to determine task priorities from potential orthosis users since, with an orthosis, the person's own arm moves during the performance of the tasks as opposed to an independent robot arm.

A motion analysis of the identified tasks was also performed for this research. Although arm motion analyses have been conducted previously, only [16] provided data on functional daily-living tasks, and only for eating tasks. As this data was insufficient for performing the orthosis simulations, as required in this study, a new motion analysis was performed.

METHOD

In order to identify the task priorities (Stage 1), telephone interviews were conducted with eleven potential users, seven women and four men. Seven subjects had limb-girdle muscular dystrophy, two had ALS, one had polio and one had C5/6 spinal cord injury [17].

In Stage 2, to acquire data for the orthosis simulations, the motions of able-bodied subjects performing 22 daily-living tasks were recorded using the stereo image analysis system illustrated in Fig. 1. Daily-living aids were used in cases where they would be required by the orthosis user. In order to follow the joint locations and define the joint rotations, five 2.5 cm spherical markers were attached to the right arm of the subject, at the shoulder, elbow, wrist, on an extension from the wrist and on the hand. In total, six right-hand dominant subjects (three female, three male), ranging in age from 22 to 44 and in height from 157 to 184 cm, participated in the study.

The joint rotations used for both the motion analysis and the simulations, shown in Fig. 2, were defined as azimuth (rotation about a vertical axis through the shoulder), elevation (rotation about any horizontal axis through the shoulder), roll (rotation about the axis of the upper arm), elbow flexion, forearm rotation (pro/supination), wrist flexion and wrist yaw (radial/ulnar deviation). A passive carrying angle was also included in the model at the elbow, rotating the plane of elbow flexion. Finger motion and complex shoulder motion were excluded.

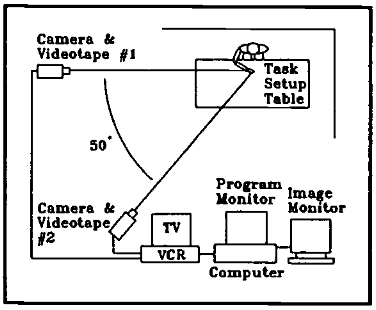

Figure 1: Motion Analysis Setup

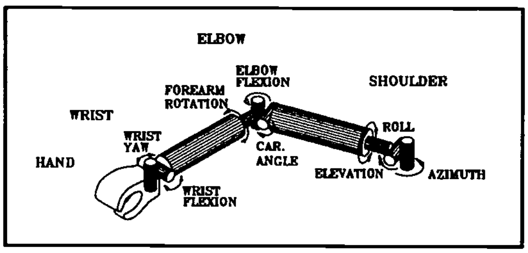

Figure 2: Joint Rotation Definitions

In Stage 3, a kinematic program was developed to determine how close a simulated orthosis could come to the desired position and orientation corresponding to the functional points for each task as derived from the motion analysis results. With up to three degrees of freedom fixed or coupled, the program evaluated whether the remaining degrees of freedom were able to compensate for the fixed degrees of freedom to achieve the functional points required for task performance, while remaining within the limb joint limits.

The software minimized a cost function to determine the actions required to move the simulated arm from an initial position to a position as close a possible to the desired position and orientation. The cost function summed the squared distance between the actual and desired endpoint positions, the squared angle between the actual and desired orientation vectors for all three orientation vectors, times a weighting factor, and a penalty function for exceeding the joint limits. A task was considered to be successfully achieved if the resulting position was within 3 cm of the desired position, within 10 degrees of each desired orientation vector, and within the joint limits, which is approximately equal to one standard deviation of the variation among the motion analysis subjects.

RESULTS

From the interviews with potential users, the question "What are the top five tasks that you would most like to do but cannot?" produced the following list of top priority tasks (with the frequency of responses given in brackets): Reaching/Picking Up Objects (9), Personal Hygiene (7), Hobbies/Crafts (7), Eating/Drinking (6), Housework (4), Dressing (4) and Strengthening Grip (4). A selection of these tasks was studied using the motion analysis.

The data from the motion analysis was analysed for joint angles, paths and orientations. Each of the 22 tasks, for each of the six subjects, was decomposed into the changes in the individual joint angles over time. The simulated orthoses were evaluated at the functional positions defined by these graphs. In order to give insight into the possibility of fixing a joint or the need to power that joint, the data was also examined joint by joint across all tasks. This indicated the importance of powering elbow flexion, forearm rotation and at least two of the three shoulder rotations independently.

Based on the computer simulations, the recommended alternatives are to power all but elevation and wrist yaw (to be fixed at approximately 53° from vertical and 2° ulnar deviation respectively) or to power all but wrist flexion and wrist yaw (to be fixed at approximately 8° extension and 2° radial deviation respectively) [18]. Fixing three degrees of freedom produced significantly more unsuccessful positions, indicating that the orthosis would not be versatile enough to be worthwhile to the user. The coupling of several joints was evaluated but did not provide an advantage over fixing a joint rotation.

The primary advantage of the first alternative, fixed elevation and wrist yaw, is the reduction in maximum torque and therefore the power consumption and bulk. However, the work envelope and flexibility of the shoulder are reduced. The primary advantage of the second alternative, fixing both wrist rotations, is to be able to reach any location that the arm could normally reach. Unfortunately, this results in little or no small-scale control of orientation except through forearm rotation and the resulting unsuccessful tasks are of a higher priority.

DISCUSSION

This research developed a new three-stage methodology for the optimal design of a powered upper-limb orthosis. In contrast to previous methods, the necessary requirements of a powered upper-limb orthosis were assessed in terms of the specific task requirements (determined by potential users), a definition of the required motion and a subsequent analysis of the capability of devices with varying degrees of freedom in order to increase the probability of user acceptance.

Work is now proceeding on the design and construction of a prototype powered upper-limb orthosis using the first design option, fixing elevation and wrist yaw. Clinical assessments of five of these devices fitted to selected users are also planned.

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SIG-14
Job Accommodation

A GRAPHICAL USER INTERFACE INCORPORATING BRAILLE AND MUSICAL SOUNDS TO ACCOMMODATE BLIND COMMUNICATIONS ASSISTANTS

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ABSTRACT

Six blind Communications Assistants (CA's) using a graphical user interface (to provide Telecommunications Relay Service) were accommodated with a Braille display to read text; a "caption line" to read graphical information; musical sounds (earcons) to identify the appearance of menus, messages, and the window containing the cursor; an optional display mode to eliminate overlapping windows; control keys to directly access form fields; and Braille labels to help locate function keys. Different CA's chose different sets of features. All six CA's are successfully using the system to provide relay service. They prefer it to the previous system, despite the addition of windowing and graphics.

BACKGROUND

Various methods have been developed to accommodate blind users of computer systems. Text can be presented via synthetic speech or "soft Braille" (a matrix of pins which rise through holes to form Braille characters) . Non-speech sounds can be added to inform the user of events such as cursor movement or appearance of objects. Adaptive hardware and software are commercially available. Examples of research are listed in the Reference section of this paper.

Relay Service. Blind employees required accommodation during a recent upgrade of a system used to provide Telecommunications Relay Service. Relay service enables people with speech or hearing impairments to communicate with non-impaired (or differently impaired) people via a text-telephone (a device with a keyboard and display, also known as a TDD or TTY). The service provides trained Communications Assistants (CA's) who relay telephone conversations by reading what the TTY party types and typing what the other party speaks. Optionally, a TTY user can utilize "voice carryover" to speak directly to the other party, or "hearing carryover" to listen directly to the other party, so the CA only needs to relay in one direction.

The graphical user interface. The new system has a graphical user interface, pictured in Fig. 1 for the convenience of sighted readers of this paper (although the interface is graphical, it is completely operated via the keyboard: no mouse or other analog pointing device is used). The screen includes a message area for error messages and other information, a billing window containing a form for entry of billing data, and a main dialog window for communicating with the TTY party. Additional dialog windows appear when the CA is communicating with two or more TTY parties at the same time. The screen also contains a "scratchpad" area for writing temporary information. To optimize use of screen space, the main dialog window and billing window partially overlap, and the scratchpad window shrinks to make room when additional dialog windows appear.

The screen also contains a graphical "Call Diagram" in which icons show the status of the phone lines (e.g. connected or disconnected, TTY or voice, etc.), and lines and arrows show the voice paths of voice and hearing carryover and the CA's headset.

PROBLEM STATEMENT

Some of our CA's are blind. They had been providing relay via a terminal emulator and a Braille display. The problem was how to optimally accommodate them in the new, graphical environment.

GENERAL APPROACH AND RATIONALE

From the start, the requirements for the new system included software hooks which would allow the blind CA's to use the new graphical user interface with their existing Braille displays[1]. This was a departure from the previous system, in which the CA's had a different interface.

The rationale for integrating the accommodation software into the standard system was that (a) it would insure that the blind CA's would always have the latest features and could thus do the full job, exactly like the sighted CA's and (b) it would enable the blind CA's to readily converse with their sighted colleagues about the system to offer and receive advice(1).

[1] I had asked CA's whether they wanted to switch to synthetic speech instead of Braille, but even CA's who had used screen readers with speech synthesis for other purposes preferred to stay with Braille for this application.

DESIGN AND DEVELOPMENT

The system design allowed modifications in the blind users' interface to be readily prototyped, in the field, without disturbing the rest of the system. I had access to the code so I could modify and supplement the accommodations in response to user feedback.

I started with minimal accommodation, and, working with training staff, simulated relay calls for the CA's so the CA's and trainers could determine if there were any problems. I then continued to add features, modify features, and test the system with simulated calls--and ultimately real calls--until all the CA's needs were met. Throughout this process, each CA had the choice of using new features, or staying with fewer accommodations.

The accommodation features included the following:

• *Braille Display*(2, 3). An 83 cell dynamic Braille display was provided for reading text.

• *Caption Line.* Information that was presented to sighted CA's as icons and connecting lines was presented as textual abbreviations(1) on a "Caption Line" so blind CA's could read it with the Braille display. The Caption Line also told the user which window contained the cursor.

• *Musical sounds.* Whenever the cursor moved from one window to another, or a menu or system message appeared(4), the system played a corresponding musical tone sequence 2 to 6 notes long (i.e. earcons (5, 6)). Some CA's needed this feature to help avoid, e.g., typing in a menu window when they thought they were typing to the customer in the dialog window, without constantly checking the cursor information on the caption line. The system also specifically warned them when they were typing in the wrong window by beeping when they typed a character that was illegal in that window (e.g. typing a space in a menu window).

• *Non-overlapping window mode..* In this optional mode, none of the windows or menus overlapped(7) (this required smaller windows, and hence small print on the screen).

• *Direct Field Access.* Control keys were programmed to jump directly to individual fields in the billing form, avoiding the need to tab through the form.

• *Braille keyboard labels.* Isolated function keys had their own Braille label. Within groups of function keys, one "landmark" key was labeled to help the CA's orient their hands for the group.

EVALUATION

The basic goal was met: all six blind CA's at the centers where the new system has been installed are on the job, providing relay service exactly like their sighted counterparts. Training averaged only a few days longer than for sighted CA's.

In addition, the blind CA's feel that the new system is easier to use than the previous system, and especially appreciate that they can now perform the same functions as their sighted colleagues (with the previous system sighted personnel had to enter the billing information). Also, the blind interface works essentially the same as the sighted interface, so blind and sighted CA's can discuss the system with a common language and vocabulary.

Two of the total of six blind CA's needed only the Caption Line. The other CA's needed additional accommodation. Four used the message sounds, three used the non-overlapping windows, one required the direct field access (it appeared to be a convenience for some of the others), and four used Braille labels.

DISCUSSION

As noted above, all six blind CA's are routinely handling relay calls the same way as other CA's.

Part of the reason for this success was that the needs of blind CA's were included from the start. This insured that the system could be readily interfaced to existing Braille displays, and gave the accommodation software direct access to the information that drove the graphical Call Diagram, avoiding the need to perform pattern recognition on the icons or lines in the diagram(8).

Different CA's preferred different accommodations. Although they all needed the Caption Line, the other features—message sounds, non-overlapping window mode, direct field access, and Braille keyboard labels—were needed by some but rejected by others. These differing needs show the importance of obtaining feedback from all the users.

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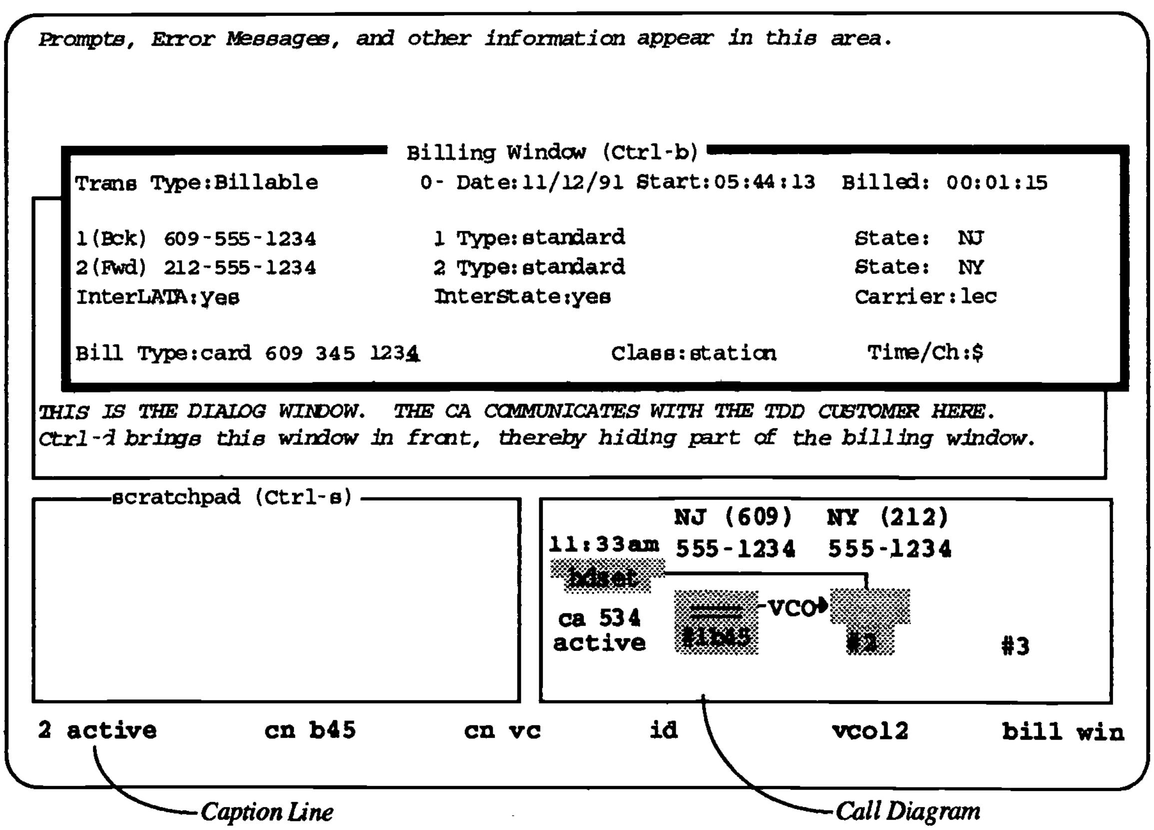

Fig. 1. Typical screen, showing the call diagram, the caption line, and the cursor in the billing window. (This figure is provided for the convenience of sighted readers of this paper, and is described in the text).

AN ANALYSIS OF WORKING POSTURES OF MANUAL WHEELCHAIR USERS IN THE OFFICE ENVIRONMENT

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Abstract
A questionnaire was developed to determine which office activities cause problems for manual wheelchair users. This questionnaire revealed that filing and writing were the activities which posed the most difficulty for subjects. Then, four subjects were chosen for each activity, filing and writing. Each subject was videotaped performing the respective activities in their own work environments and then asked to complete a questionnaire about sites, intensity and frequency of discomfort felt. Because previous researchers have found a direct relationship between inappropriate working postures and discomfort, it was possible to identify probable sources of discomfort in the videotaped working postures of the subjects. Discomfort at the low back was found to be the most severe complaint in both activities of filing and writing.

Background
With the recent enactment of the Americans with Disabilities Act (1) and increase in the disabled worker population (2, 3), modifications for accessibility and office furniture will be required. This study was performed to increase knowledge and stimulate further research on the needs of wheelchair users in work environments so that *appropriate* modifications can be made.

Research Questions
The objective of this study was to answer the following questions:
- What office tasks appear to be the most potentially detrimental to manual wheelchair users due to the poor design relationship between office equipment, manual wheelchairs and their users?
- What body regions of subjects experience discomfort due to performing the tasks which appear to be the most potentially detrimental to manual wheelchair users?
- What detrimental postures are being imposed on users due to an inappropriate design relationship?

By answering these questions, the source of major design problems in manual wheelchair work environments can be identified and then defined. Once defined, a plan for improvement and modification can be *effectively* implemented.

Method
This study consisted of two phases (Fig. 1). In Phase I, Questionnaire 1 was developed to determine which office tasks cause difficulty for manual wheelchair users. Copies of this questionnaire were mailed to 140 potential subjects. Sixty of the subjects who responded with completed questionnaires met the subject criteria for this study -- adult manual wheelchair users who work in office settings. The responses to Questionnaire 1 were then analyzed.

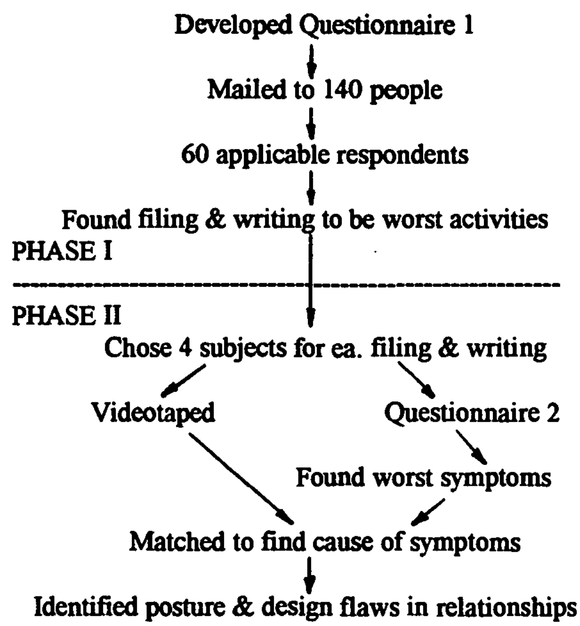

Figure 1. Flow Diagram of Method Used.

According to van Wely (4), level of comfort is an indication of how potentially detrimental a posture can be. The more discomfort felt, the worse the posture is. If the posture is held repeatedly or intensely, severe damage to muscles, bones or tendons may result. Also, prolonged, frequently-sustained, static postures, particularly awkward postures, result in fatigue and discomfort and often contribute to various musculoskeletal disorders and work inefficiency (5). Based on these findings, several factors were chosen to be considered in determining which tasks were most problematic from the Questionnaire 1 responses. They are listed as follows:
- feeling physical discomfort

- intensity of discomfort
- feeling tired easily
- perform task frequently (≥ 4 hours/day)
- feels that there should be an easier way to perform the task (indicating a desire for change).

The two activities which possessed the most responses in these areas were chosen to be analyzed in Phase II. *Filing* and *writing* were the two activities found to be most problematic.

In Phase II, four subjects were studied performing *each* activity (writing and filing). The subjects were videotaped performing their designated activities for approximately fifteen minutes at their worksites. Immediately following videotaping sessions, subjects were asked to complete a questionnaire. Questionnaire 2 was based on studies performed by van Wely (4). Van Wely developed a table of bad postures with corresponding probable sites of symptoms for each posture and then confirmed these relationships. For example, sitting without a lumbar support would probably give rise to pain at the lumbar region of the spine. Thus, Questionnaire 2 was designed to identify locations of discomfort which subjects felt were due to writing or filing.

Results

Table 1. Top Activities With Potentially Detrimental Characteristics.

Potentially Detrimental Characteristics	Top 3 tasks with highest percentage of YES answers from Questionnaire I
physical discomfort	1.) writing (33.9%) 2.) reading (28.6%) 3.) filing (25.5%)
tired easily	1.) writing (27.6%) 2.) filing (26.4%) 3.) reading (26.3%)
done frequently (> 4 hours/day)	1.) reading (19.6%) 2.) computer (16.4%) 3.) telephone (13.6%)
intensity of discomfort	1.) filing (30%) 2.) none (16.7%) 3.) writing (13.3%)
should be an easier way (indicates desire for change)	1.) filing (58.7%) 2.) writing (42.9%) 3.) copy machine (39.6%)

After the body's specific areas of discomfort were identified using Questionnaire 2, analysis of working postures on the videotapes was performed to locate possible *sources* of discomfort. This resulted in discussion of possible design flaws in the human-equipment relationship which might cause discomfort.

The three activities which received the highest percentage of responses from Questionnaire 1 for each potentially detrimental characteristic mentioned above are listed in Table 1.

Filing and *writing* were the activities which contained the greatest number of potentially detrimental characteristics (listed in four out of five) and were chosen to be studied in more detail in Phase II.

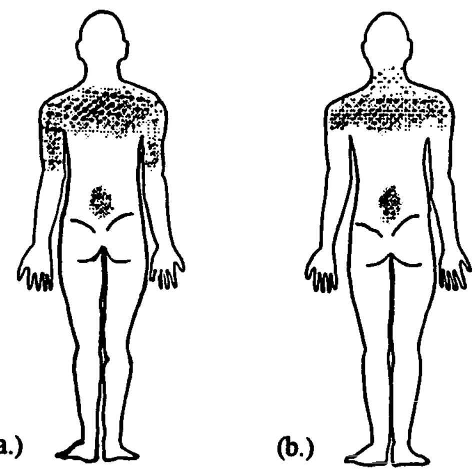

Figure 2. Sites of Discomfort Indicated by Subjects Due to (a.) Filing, and (b.) Writing.

For this group of subjects, the lumbar region was the area which symptoms of discomfort is most commonly felt due to filing (Fig. 2a). Three out of the four subjects indicated that they feel discomfort in this region. Two subjects feel discomfort in the trapezius, rhomboideus, levator scapulae, and shoulder and upper arm regions.

The most common site of discomfort reported by the subjects who performed writing was also in the lumbar region (Fig. 2b). Three out of the four subjects said they feel discomfort in the lumbar region during or after writing. Two of the subjects feel discomfort at the center of the upper back, shoulder regions, and cervical region. Two subjects said they feel symptoms on the sides of the neck.

Discussion

A poorly designed activity possesses potentially detrimental characteristics. Each activity studied in Phase I was evaluated based on the amount of physical discomfort it caused, how easily subjects felt fatigued, how frequently subjects performed the task, the intensity of discomfort felt, and a desire for change in the way the task is performed. The two office activities which possessed the most potentially detrimental characteristics were filing and writing.

The main body regions where subjects indicated feeling discomfort due to filing were the lumbar region of the spine, upper back, shoulders and arms. Filing required subjects to bend over forward at the lower back to access the drawers of the filing cabinet. The lower the drawer, the more subjects needed to bend forward. In addition, subjects needed to twist their torsos to extend one arm further forward, stretching to reach files. Such postures are probable cause of discomfort in the lower back. Higher drawers required subjects to reach upwards and tilt their heads up, frequently not being able to actually see the contents of the drawer. Reaching upwards probably causes discomfort in the shoulders and arms. The drawer which required least potentially detrimental motions to access was the third drawer up from the floor (about 3 to 4 feet from the ground). Subjects need a filing system which allows them to get their chairs under the drawer so they can approach the system without bending forward, twisting and stretching to reach.

For writing, subjects felt the most symptoms at the lumbar region, upper back and shoulders. Writing required subjects to sit in bent forward positions without any support for the lower back. Lumbar supports would help the lumbar spine retain its natural curve and minimize stress and discomfort on this part of the back while subjects are working in the seated position. Desks were raised to facilitate getting legs underneath the desks. In doing so, desktops became too high causing subjects discomfort in the shoulder and upper back regions. A compromise needs to be met between the desk height and desk opening for an appropriate user fit. Thinner desks without a drawer would be effective.

In this study, we were able to conclude that filing and writing are the office tasks which contain a high potential for detrimental characteristics. The lower back was the most effected body region for the subjects in this study. However, it was not possible to conclude on the following issues which would provide much needed information to devise appropriate modifications in the wheelchair work environment:

- Is the information in this study representative of the adult manual wheelchair office worker population of the United States of America. Further demographical study using more subjects on this population is required.
- Are these problems wheelchair user specific?
- Are van Wely's findings on the relation of specific sites of discomfort with particular working postures equally applicable to the population of people with disabilities?
- Do other population sub-groups and other wheelchair types experience similar problems?
- What problems exist with other office activities?

In summary, the tasks of filing and writing were found to be poor tasks for the group of subjects in this study. They both caused discomfort for subjects, particularly in the lower back region. Although some suggestions on ways to correct problems found in this study were mentioned here, further research is required to determine their effectiveness. More research is warranted on the *scope* of wheelchair work environments to facilitate *appropriate* modifications in the future.

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BUSINESS AND REHABILITATION: A PARTNERSHIP ON WORK-SITE ACCOMMODATION

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ABSTRACT

Supported Employment (SE) and ADA (Americans with Disabilities Act) are very common buzz words in rehabilitation in the 1980's and 1990's respectively. The job development, job analysis, job placement, job site accommodation, and on-going job coaching are important factors in Supported Employment. The SE program only works when the employer, rehabilitation staff and consumers work in harmony. Supported employment for Allen at Marriott, as an individual dishwashing operator, was possible because Marriott did all the recommended modifications of the dishwashing machine. This not only increases safety for Allen but increases productivity as well.

WORK SITE ACCOMMODATION:

The Habert Industrial Dishwashing Machine washes pots, pans, dishes, cups, glasses, silverware, etc. for very busy hotels like Marriott Corporation. They become busiest immediately after banquets. One operator loads the items on the feeding end of the conveyor belt and another operator unloads and stacks the items in their proper places. The operating process gets interrupted if small items fall through the gap between the conveyor belt and the edge of the dishwashing machine.

The operator, Allen, needs to stop the conveyor belt by pushing a switch on the panel to retrieve the items from the bed of the dishwashing machine. Failing to stop the conveyor belt before retrieving the object could result in hand/finger injury. Allen's left hand became caught in the mechanism that moves the belt. He lost the tip of his ring finger and had two broken fingers. However, Allen was able to return to work at Marriott after four months of therapy.

After reviewing the worksite, a number of modifications were suggested. Marriott's manager submitted the modification plan (for adaptations) to the manufacturer who also maintains the dishwashing machine. Habert made the following modifications and the cost was only $200:

1. Relocating a switch which automatically stops the conveyor belt once the metal guard is lifted to retrieve items.
2. Providing a stainless steel guard between the conveyor belt and the edge of the machine as extra precaution.

RESULTS

As modifications increase safety, speed of operation, and are reasonably priced ($200 per machine), Marriott Corporation requested Habert to install such adaptations to the dishwashing machines at their other locations.

Allen, with developmental disabilities, began working at Marriott on February 27, 1990 as a Utility Aisle Attendant at the rate of $4.75 per hour. The job coach counselor supports Allen socially, psychologically, and with job site counseling which helps him to retain the position. His part-time supported employment position became a full-time one with a series of pay raises - $4.75, $5.95, $6.30, and $6.65 in July, 1990, January, 1991, November, 1991, and November, 1992 respectively.

Allen is dependable, uses public transportation, cordial to co-workers and supervisor, and performs duties satisfactorily. After the injury, he follows the safety rules very well. His productivity is 80% to 85%, which is below average but his employers think that his dependability, understanding of job tasks, and four years of experience compensate for the productivity. The turnover in this position is high and constant hiring and training of new employees is a nightmare, as well as loss of resources for the employer.

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MODIFICATION OF INDUSTRIAL HOSE NOZZLE AND WORK AREA FOR WORKER WITH ARTHRITIS

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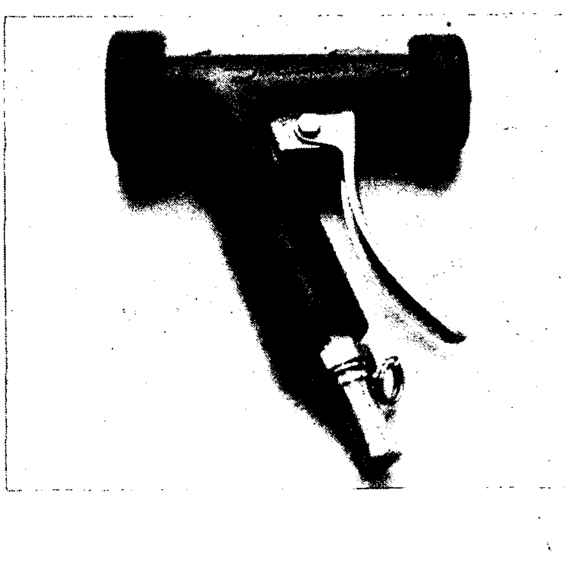
ABSTRACT

Industrial controls are often designed for heavy-duty usage and durability, with ergonomic considerations given secondary importance. An industrial-grade hose nozzle handle was found to require activation force at the user's palm, presenting difficulty for a worker with arthritis. Modification of the nozzle and the work area are described. The modifications resulted in comfortable use by the worker with arthritis, as well as another worker in the area.

BACKGROUND

While ergonomic considerations are finding their way into worksites, design factors which ensure performance under heavy-duty conditions over long periods of time often appear to take precedence. One goal of the application of Assistive Technology is the improvement of the ergonomic design of devices, with no reduction in the industrial performance.

Referral was made regarding worksite modification for a client with arthritis at a local baking facility of a national baked goods company. The worker was employed as an Equipment Cleaner, which requires her to clean machines and work areas where ingredients are mixed before baking. This work takes place in an area approximately 20" x 35", and is performed with a single high-pressure hot water line, with a Strahman Model M-70 nozzle attached (Figure 1). The cleaning activity is usually 3 - 4 hours in duration.



The nozzle is designed to require the user to activate the lever arm with the center of the palm. The application of force in this area is problematic for use of any tool (1), and caused discomfort for the individual at her right wrist and hand. The client's accuracy in using the nozzle with her left hand was decreased, and it was also felt that discomfort would eventually develop there as well. Modification of the nozzle and other aspects of the work area were discussed with the client, supervisor, and company health care manager. The company had already investigated nozzles made by other companies, and found their design to be the same as the existing unit.

The use of the nozzle's existing locking ring, to lock the lever in the "on" position, was not an option, as the user had to continuously change the flow of water from a wide spray to a concentrated stream to clean some machine components.

OBJECTIVE

The goals included stabilization of the client's right wrist (as per written specifications by her physician) and the reduction in the amount of work being performed by the client's right wrist and hand as she moved about the work area. The latter goal was known to involve the modification of the nozzle lever, but also included interventions to reduce the amount of work being performed while maneuvering the hose around the work area.

Other goals included the shared use of the equipment by other Equipment Cleaners, and the use of materials suitable for a clean, and at times wet, environment.

METHOD / APPROACH

The hose and nozzle were relatively heavy, and difficult to move around the work area. As a worker moved about, he or she would need to pull and swing the hose around the machinery. It was felt that this also contributed to the discomfort experienced by the client.

The following equipment was issued to stabilize the client's right wrist and reduce the amount of work involved in maneuvering the hose:

- Use of a commercially-available elastic wrist-hand orthosis with metal stay. This was provided to stabilize the angle of the

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client's wrist, as per recommendation from the client's physician.

- Installation of two stainless steel rings on the hose, approximately 3' and 6' from the nozzle, using stainless steel hose clamps. These would serve as attachment points for hose support equipment.
- Installation of three tool balancers, anchored to the mixing machine's framework, to provide support for the hose as certain areas were being cleaned. This enabled the client to be responsible for the support and manipulation of the last 3' to 6' of hose as she was working, not the entire hose.
- Provision of a nylon tool belt, with modified hammer holder accessory, to hang the hose ring as the client was walking around the machinery. Again, this reduced the amount of hose the client was pulling with her upper extremities, and transferred that load to the client's lower extremities.

The key modification provided, however, was the adaptation of the nozzle lever, to eliminate the force at the client's palm. This was achieved through the attachment of a 6"-diameter, semi-circular T-shaped adaptive handle, fabricated of 1/2"-thick high-density polyethylene (HDPE) (Figure 2). The adaptive handle was attached to the existing nozzle at the two pivot bolts, using two L-brackets from stainless steel adjustable-angle seating hardware. Four 1/4"-20 round head stainless steel machine screws and four 1/4" stainless steel flat washers were used to attach the L-brackets to tapped holes in the adaptive handle.

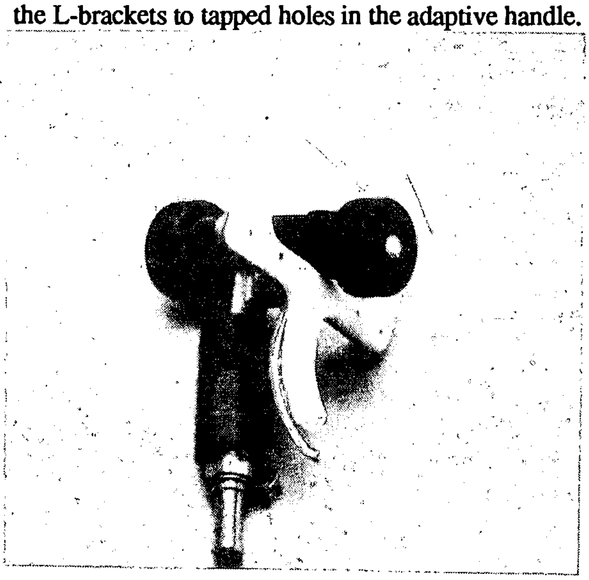

Figure 2

The central vertical section of the adaptive handle was curved to match the existing nozzle lever curve. As such, the use of the top of the adaptive handle is totally external to the existing nozzle lever; pulling back on the top section of the adaptive handle forced the vertical section against the existing lever to activate the water flow.

RESULTS

The client was able to activate the water flow without any force present at her palm, by pulling back on the center cross-piece or top of the adaptive handle (Figure 3).

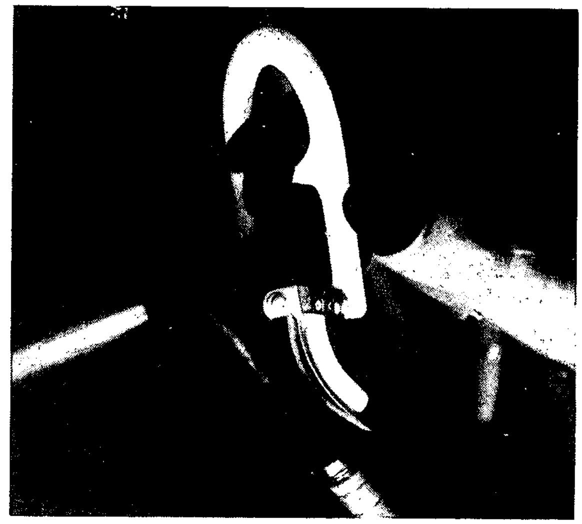

Figure 3

The client was also able to maneuver the hose around the work area with no discomfort developing in her hand and wrist. She was able to attach and remove the hose from the adapted tool belt or the tool balancers easily (Figure 4).

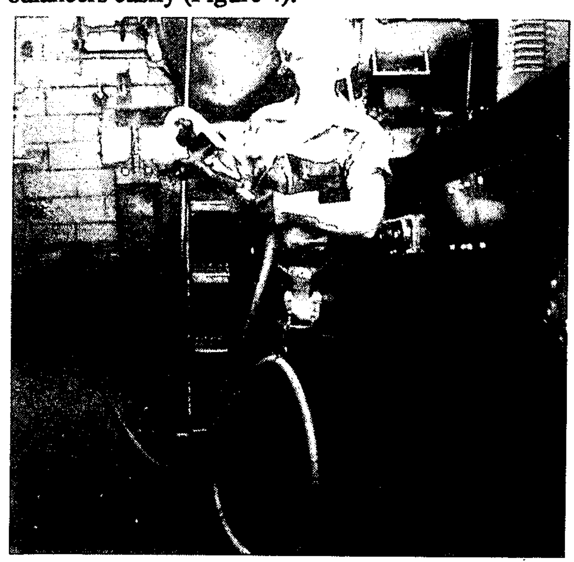

Figure 4

MODIFIED INDUSTRIAL HOSE NOZZLE

Another Equipment Cleaner performed the job activities using the adaptations and reported that the job was not only easier, but safer in that the tool balancers eliminated the problem of tripping over the hose as a given area was being cleaned.

DISCUSSION

As with many worksite modifications, the intervention involved the modification of a specific tool combined with changes in the work environment. This combination of modifications achieved the overall goal of the worker with arthritis being able to perform the work activity without discomfort. Other workers having the same work activities are able to perform the job in the same manner, or utilize the modified equipment.

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(1) Chaffin, DB and Andersson, GB. *Occupational Biomechanics*. Wiley & Sons, Inc., New York, NY, p. 420-421, 1991.

SOURCES

Hose Nozzle
Strahman Valves, Inc.
3 Vreeland Road
Florham Park, NJ 07932 USA
(201) 377-4900

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LONG-ARMED BOTTOM WIPER WITH A DETACHABLE HANDLE

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ABSTRACT

A long-armed bottom wiper with a detachable handle is designed and fabricated for an office worker with very short upper limbs and mild upper limb impairment. It holds toilet paper firmly, comes apart in two sections for inconspicuous portability, and has features that makes it highly functional for its intended purpose.

BACKGROUND

A female office worker with very short upper limbs and mild upper limb impairment found commercially available bottom wipers unsatisfactory for a variety of reasons. Toilet paper tended to fall off the type without a clamping mechanism (Fig. 1a). Those devices with a clamping mechanism (Fig. 1b,c) were found to have the wrong shape and reach as well as demanding on upper limb function. The most satisfactory device had been a custom made bottom wiper which has a long-arm which is shaped and sized according to her needs. At the end of the arm is a gondola shaped device, fashioned out of splinting material, with a latch falling towards the hollow of the gondola. The latch bears down on the toilet paper which is wrapped around the gondola. Shortcomings with this device are that it is difficult to take along because of its length, it traps waste because of the large space in the gondola and crevices between the gondola and the hollow handle, and the user found the latch difficult to operate and often unreliable. As a consequence, this person had been enduring a lot of inconvenience, especially at work.

RATIONALE

A bottom wiper should be able to hold on to toilet paper firmly during use. It should have the right size and shape for the user. The device should be easily to operate, hygienic, discreetly portable and durable.

STATEMENT OF THE PROBLEM

Design and fabricate a functional bottom wiper for the client for use both at home and at work.

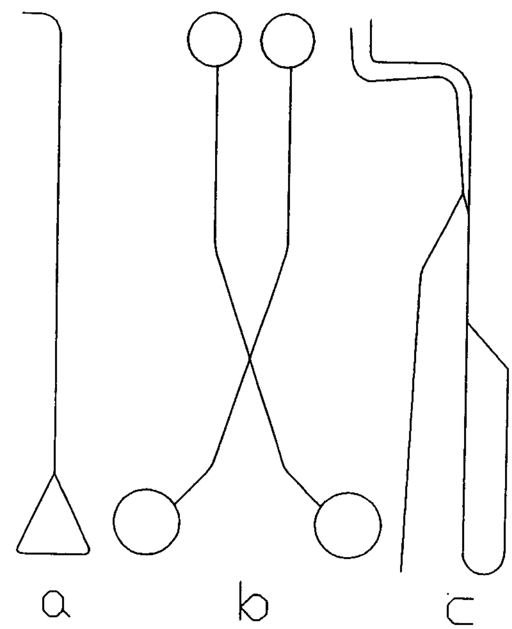

Fig. 1 Configuration of several commercial bottom wipers

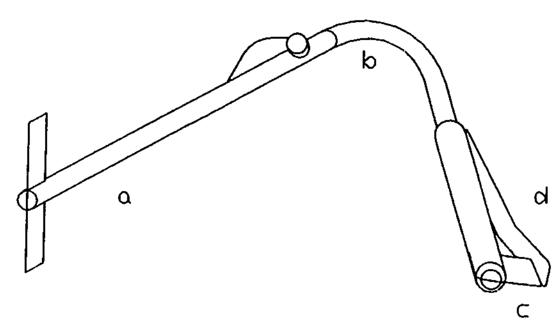

Fig. 2 Long-armed bottom wiper with a detachable handle (initial version)

DESIGN

The bottom wiper is shown in Fig. 2. It is constructed with aluminum and plastic (PVC). The long aluminum tube handle has a straight section [a] and a curved section [b] which are joined together by a connecting PVC rod fixed on the curved section. At the end of the straight section is a T-shaped hand-grip. At the end of the curved section is the toilet paper gripper which consists of a solid PVC rod with a flat PVC tip [c] that projects down

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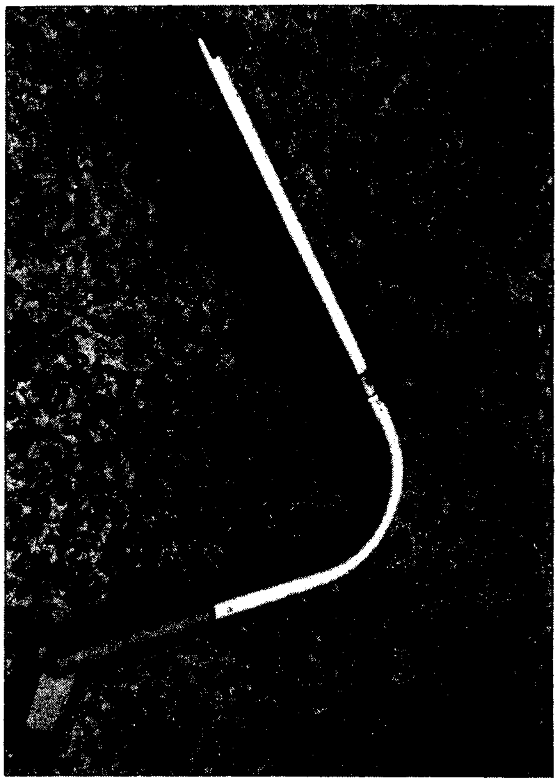

Fig. 3 Long armed bottom wiper with a detachable handle (final version)

at 30 degrees, and an angled PVC flat that functions as a swing-away clip [d].

In use the two sections are first assembled and secured using a thumb screw tied to a nylon string attached on the straight section. The clip is then swung away from the tip so that toilet paper can be wrapped around the body of the gripper. The paper is held down securely when the clip is swung to press against the tip. The paper can be easily shaken loose when the clip is swung away from the tip.

The PVC connecting rod at one end and the toilet paper gripper at the other end effectively seals the curved section (b). All joints in this section is sealed with PVC glue. The whole device weighs about 90 grams.

EVALUATION AND DEVELOPMENT

After a few days of use, several changes were made according to user feedback. Fig. 3 shows the final version of the device. The length of the handle was increased slightly for better reach. A finger like projection was incorporated at the upper end of the gripper to facilitate wiping. The thumb-screw, which the user found difficult to operate because of problem with dexterity, was replaced with a push-pin.

The user has been using this device now for over three years and found the device functional, reliable, inconspicuously portable and durable.

DISCUSSION

In the open job-market, the disabled has to show that they can perform in their designated job and be able to self-care inconspicuously, which able-bodied persons have taken for granted. This is a case where a simple aid can facilitate this process.

ACKNOWLEDGEMENT

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THE SUCCESSFUL INTEGRATION OF ASSISTIVE TECHNOLOGY AND JOB DEVELOPMENT FOR AN INDIVIDUAL WITH A DISABILITY: A CASE STUDY

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ABSTRACT

This case study illustrates how customized assistive technology was successfully used to facilitate the process of job searching and job development. Tan, age 32, is the individual on whom we focus in this study. He had previously worked for ten years at a sheltered workshop before obtaining a job at a local K-mart store. Customized technology has played an important role in helping him perform his job duties at the K-mart garden department and continues to act as a catalyst for performing other job opportunities. The technology was developed through a team effort by Tan, engineers and technical support staff at the Interwork Institute and Sharp Rehabilitation Technology Service, and Tan's managers and co-workers at K-mart. Technical setbacks have been a part of the development process, but a committed effort by all involved have made this story a success. The job has served to increase Tan's confidence in his own abilities as well as make his co-workers and managers more aware of his abilities. Tan's confidence on the job has encouraged him to branch out in other aspects of his life as well.

BACKGROUND

Assistive technology can expand the job opportunities available to an individual and greatly enhance one's abilities at the workplace. If compensatory strategies or modified work methods do not help the person reach the desired goal(s), a need for technology may exist. The assistive technology process then involves investigating commercially available technology and using it when appropriate. Experience has shown that often a commercially available device may need a customized adaptation to match the worker's abilities.

Combining the use of customized assistive technology with job development is a delicate process. While an employer generally wants a job opening filled as quickly as possible, the successful development of technology often requires much effort in research and development (a time intensive process). Even though all parties involved know that the customized technology is in the developmental phase, on-the-job technology failures are not tolerated for long by either worker or employer. Consequently the technology problem solving process must facilitate the worker's functional performance yet occur quickly enough to fulfill the employer's needs. Successful transition into the workplace requires open lines of communication, and cooperation, between the employer, the employee, the job development staff and the technical staff. This case study provides an example of how this process can work and how the successful job transition positively affected other aspects of Tan's life.

Tan, age 32, has a condition of cerebral palsy. As a consequence he cannot walk and has limited upper extremity function including weak hand grasp and finger pinch. However, he can operate an electric powered wheelchair independently using a joystick controller. His speech is intelligible although somewhat difficult to understand at times. Tan had worked at a segregated, sheltered workshop since he graduated from high school in 1982. At the workshop his main job duty included bulk mail handling, which involved labeling, collating and stuffing envelopes. His wages depended on both an hourly rate and a piece rate (paid per task completed). He worked a five hour per day, five day work week and received an average paycheck of fifty dollars per month.

Tan lives at home in a very protective family situation. His parents and siblings had been skeptical of his abilities, and did not believe he could perform a job independently. Possibly as a result of this atmosphere, Tan's own self confidence was low and he was even afraid to leave the house and conduct activities on his own.

OBJECTIVE

Our objective for Tan was to help him obtain a job at a local business. The experience would expand his opportunities to meet people, explore new interests and increase his self confidence. Assistance to help Tan make this transition from the sheltered workshop was made possible through two federally funded demonstration grants: "Applications of Technology" and "Project Real Move".

The objective of the "Applications of Technology" grant is to expand an individual's opportunities vocationally, scholastically, recreationally or residentially through the use of customized technology. The objective of the "Project Real Move" grant is to help convert a sheltered workshop agency into an individualized employment and community integration support service. The job development process emphasizes supplementing "natural supports" which commonly exist in a business setting to help an individual perform his/her job and offer that individual a higher level of independence.

THE PROCESS

Tan wanted to work at the local K-mart store because it was within close proximity to his home and it provided the type of atmosphere and opportunities he thought he would enjoy. When contacted by the Interwork job developer staff, the K-mart store manager and human resources manager expressed their interest in Tan by arranging an interview for a position in the garden department.

After the interview (7/19/93), a team of two job developers and a technical support staff person met with Tan, the store manager and the garden department manager. The purpose of this meeting was to get a very detailed description of the job duties involved. The input from the garden department manager was essential for the technical support staff and engineers who would develop the required technology. The primary job task was to water all the garden department plants and trees. The job was previously accomplished by a person holding a 3 ft aluminum "water wand" attached to a hose. The worker controlled the water flow valve by turning a short lever which was grasped between the thumb and index finger. Tan was not able to hold the water wand or operate the valve due to his weak hand grasp and limited finger pinch. At this point, the employer showed some skepticism regarding Tan performing the job essentials but was willing to let our technical support staff develop and apply the necessary technology. Through questioning and listening to Tan, as well as observing his abilities through "mock-ups" and trial device use, we were able to create some solutions.

The technology solutions to operate the waterwand were based on his ability to grip a long lever (four inches), and his ability to operate the powered wheelchair very accurately. The process to set up/remove the waterwand for Tan had to be easy and quick, since co-workers would be providing this assistance. Within two weeks of the initial interview, the first working prototype was developed. It consisted of a gas line valve (with four inch lever arm) attached to the water wand, which was attached to the hose. The gas line valve was mounted on a ball and socket type of hardware to allow adjustment for the orientation of the water wand. The hardware was then attached to an inverted "U" frame which slid into brackets on Tan's wheelchair. Tan demonstrated his skills to orient his wheelchair, turn on the valve to begin watering, and then turn it off to travel to the next watering area.

This initial prototype worked very well and heightened the awareness and enthusiasm of Tan's co-workers and the manager. Tan was also visibly pleased. After a week, the job facilitator placed at the K-mart store, to help Tan make the transition, was no longer needed. The co-employees at the garden center were more than happy to help attach the device to his wheelchair, untangle the hose, or direct the water wand when needed.

Tan was now working three, four hour days per week. However, there were new technical obstacles which needed to be resolved. The garden hose/waterwand valve joint tended to leak, causing Tan's lap to get wet. The strain on this junction was excessive due to insufficient strain relief on the hose when pulling it long distances or dragging it around the corners of the cement block plant stands. Quick solutions included a nylon cinch strap hose strain relief which attached to the lower frame member of the wheelchair. Hose friction and chaffing against the cement blocks was eliminated by attaching four inch diameter PVC tubing which was cut in half sections and attached to the block corners with cable ties.

Another area addressed was Tan's posture when sitting in his wheelchair. His planar seating system was worn and did not afford proper support necessary to prevent forward hip slippage and a resultant sacral seated posture. Besides causing unnecessary fatigue and effort required to maintain a midline upright seated posture, the worn seating system required more effort from Tan as he performed his job duties. Ideally his seating concerns would have been addressed prior to the K-mart job opportunity. However, no one wanted to jeopardize losing the job offer while waiting for a seating assessment and funding approval. Fortunately a new anti-thrust seat, contoured back, and lateral trunk supports were obtained and fitted within one month of starting work at the store. The change was significant as it improved body posture, caused less fatigue, and improved his functional performance. The importance of good seating support cannot be overemphasized and should be addressed as early as possible.

Additional technology modifications were completed to solve other problems. Some of these solutions were easily accomplished, while others still continue to be developed. Our experience has shown that technology which can be quickly adjusted and maintained by Tan's co-workers requires less attention from the Interwork technical support staff.

RESULTS

Tan's demonstrated abilities and perseverance to "get the job done" have generated more opportunities at the store. A short time passed before an extensible water wand was developed which allowed Tan to water the hanging plants in the nursery. Currently an attachment for a leaf blower is being developed to enable him to sweep the aisles of the garden department before he waters the plants. We are also working on a duster attachment for the wheelchair such that Tan can dust the baseboards on product exhibits along the aisles inside the store.

Tan has progressed notably in his willingness to venture into new activities and interests outside of work. Five months ago he was afraid to leave the house on his own. Now he goes to a local Chinese restaurant everyday after work for lunch. The staff there know him so well that his favorite meal and a beer are awaiting him when he arrives. He has formed strong friendships with many of his co-workers, whom he goes out with on the weekends and some weekday evenings. He now calls the local transportation company and schedules his own travel arrangements to get to the local mall, or to meet with friends. His next goal is to move out of his parent's home and into his own apartment with a roommate. He also hopes to expand his job duties for more hours. He is more self sufficient monetarily as he is earning $4.30 per hour at K-mart versus averaging $0.50 per hour at the sheltered workshop.

DISCUSSION

When developing technology, more research and testing often translates into a better, more reliable product. However, often times in the job search and development process, expedient production of customized technology is essential in securing and maintaining a position (for a person dependent on that technology to do the job).

Our experience has shown that the challenge for an engineer working on customized job accommodation technology is a task which requires fast, quality production of working prototypes. Also inherent in this field is the necessity to make quick, accurate modification to the technology based on information learned from actual on-the-job testing and observation.

For this reason the cooperative team approach is needed. An employer committed to the work transition process will allow the technology to develop as the employee is performing his/her job duties. In this way the employee's performance can be optimized to meet the specific needs of the job. Readily available technical support staff are needed to help solve technical problems quickly with the least amount of loss in worker productivity.

While the technology used by Tan at K-mart has been successful in allowing him to perform the job, it has not been without technical challenges. The cooperative support effort of Tan, K-mart, Interwork, and Sharp Rehabilitation Technology Services has made this a successful venture.

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"Community Based Projects: Project Real Move"

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ASSESSMENT AND TRAINING DEVICES FOR WORK PLACEMENTS AT THE HISSOM MEMORIAL CENTER

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ABSTRACT

This paper discusses several devices constructed to aid in the assessment and subsequent training of individuals for sheltered jobs.

INTRODUCTION

As part of a residential facility for developmentally delayed individuals, the Work Assessment Center and the Outward Bound Workshop utilized numerous commercially available switches appliances and reinforcers with clients. When a custom device was required, it was constructed by the Rehabilitation Engineer and the switch shop technician.

FISHING LURE PACKAGING

The Outward Bound Workshop had a contract to package fishing lures. To keep the lures in good condition, they were bulk packed in cooking oil and salt. The packaging process had several steps:
(1) Count ten lures out from bulk packaging
(2) Orient five in each direction,
(3) Place in bag with claws showing
(4) Staple cardboard header to bag
(5) Punch a hanger hole in plastic bag.

This process required several custom devices.

Counting Aid

Outlines of ten lures were painted on a board, for those with more ability, the outlines were reversed for five lures.

Fishing Lure Inserter

To aid in holding the bag open as the lures were inserted, several inserters were fashioned. These consisted of a thin flat piece of plastic with upturned, tapered sides.

Adapted Stapler

An electric stapler has been used in several contracts, most recently to package fishing lures. Initially an unmodified Swingline 5000 electric stapler was used, controlled by a user switch connected to an AC control box. Although the switch user controlled AC power to the stapler, actual stapling was performed only when the job coach moved the plastic bags into position moving a sensor attached to the activation switch. Clients did not readily learn the requiredjob tasks because they were one step removed from activating the stapler. When asked to consult, the rehabilitation engineer took apart the stapler and found a custom integrated circuit and a slightly more complex activation switch than expected. After consulting with the manufacturer engineer, a low voltage relay circuit was designed and built. This now allows clients to perform the actual stapling.

Photo 1: Adapted Stapler

Electric Hole Punch.

To allow clients operation of a hole punch, control electronics were developed to pulse a washing machine solenoid attached to a hand hole punch. The pulse circuitry prevents the solenoid from overheating if the user switch is activated too long.

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Photo 2: Electric Hole Punch

WORK AIDS

Paper mover/shredder

Staff determining appropriate jobs for switch users, found a need for documents to be shred. Training was implemented by using appliance relays for switch control of electric shredders. While this allowed some aspects of the shredding process to be done by a switch user, considerable staff support was required to

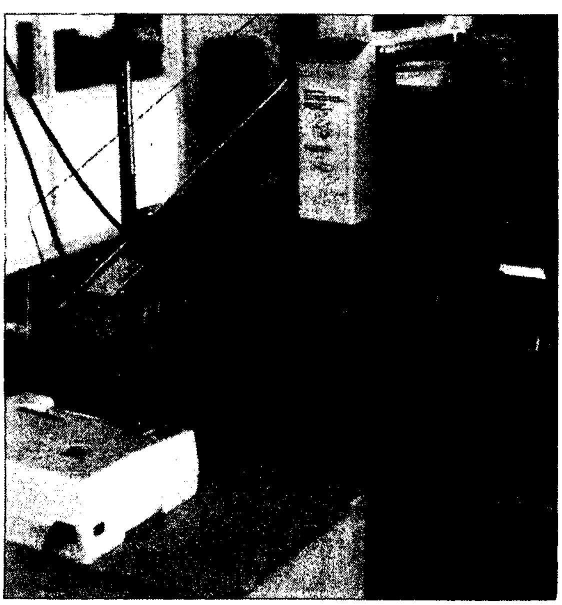

Photo 3: Paper Mover/Shredder

place five or fewer sheets in the shredder each time. In order to increase independence, surplus paper movers were used to hold several hundred sheets of paper. The Toshiba MP-2 and MP-3 or Panasonic KX 1125 paper movers normally feed paper to a copier or printer, but were modified for shredding use. The electronics controlling paper ejection were replaced by a simple timer and power transistor. Adjustment of the timer allowed the paper ejection motor to eject one sheet for each activation of the user switch. Paper then slid down a clear chute to the shredder. Users had to learn to not overload the shredder and to call for help when the paper chute clogs or the shredder jams.

Can Counter

To reinforce training an individual to place crushed aluminum cans in a trash barrel, a system was developed to count cans as they were thrown into the barrel. After unsuccessful attempts using mechanical can sensing, photoelectric sensing was utilized. The can sensor signal was sent to a counter. A staff settable switch allowed reinforcement every one to ten cans. When the count was matched, a staff settable timer was activated turning on a reinforcer, for this individual, a radio. A LED display indicated count.

Three Digit Counter

The Work Activity Center requested a display of user activation counts for use during repetitive activities. Requirements included ability to count to 199, and large display for use by the sight impaired. This resulted in a three digit counter using 4 inch LED numbers. Interface electronics were used to convert the 5 volt signals from the counter integrated circuit into the 12 volt high current signals necessary for the display. The compare feature of the IC was utilized to activate a reinforcer when a preset count was reached. Staff used a three digit thumb wheel switch to set the desired compare number.

REINFORCEMENT AIDS

Scanning Traffic Light

For reinforcement purposes, a Radio Shack traffic light was modified to allow a user to step scan through the three lights.

Bubble Machine

The Work Assessment Center requested a hand cranked bubble machine be motorized to enable switch access. In evaluating the unit it was decided to start from scratch basing the design on a 12 volt dc gear motor. A fan blade was fabricated, attached to the motor shaft, and the motor mounted in a large coffee can. A disc with several holes around the perimeter was mounted on the low speed shaft. The disc is partially submerged in a tray of soapy water. A wall transformer powers the unit through a transistor. The transistor reduces the current passed by the user switch. When activated, air is blown across the slowly rotating disc, releasing soap bubbles into the air.

Photo 4: Bubble Machine

Please note: The Developmental Disabilities Services Division of the State of Oklahoma is in the process of closing the Hissom Memorial Center and transferring residents to the community, expecting to be completed by April, 1994.

ACKNOWLEDGEMENTS

The Developmental Disabilities Services Division contracts with the O'Donoghue Rehabilitation Institute for rehabilitation engineering services. The author wishes to thank John Bennett SP-CCC, former head of the Outward Bound Workshop, and Wanda Wedel, former head of the Switch Assessment Center, for their device suggestions and support. The author also thanks Ollie Brown, Switch Shop Technician for greatly assisting in implementing these designs.

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SIG-15
Information Networking

SATIRN II* A COMPUTERIZED INFORMATION AND REFERRAL SYSTEM FOR ASSISTIVE TECHNOLOGY AND INDIVIDUALS WITH DISABILITIES

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Abstract

The provision of accurate and timely information and referral to appropriate sources is important for all individuals, particularly so for individuals with disabilities and their families who may be trying to address a number of issues. The SATIRN II Information and Referral software program and database developed by the NYS Office of Advocate for the Disabled serves as a helpful tool to quickly obtain information on programs and services which may be specific to people with disabilities or broader based to meet the needs of various populations. The program and database are provided at no cost to public and private not-for-profit agencies, including public libraries. Technical assistance and support is provided to SATIRN II users by professional information and referral staff between 9 a.m. and 5 p.m, five days a week, via a toll-free number. It is also available from the private contractor who designed the computer program. SATIRN II can also be accessed via the agency's electronic bulletin board system's 800 number, 24-hours a day, 365 days a year. This paper describes the SATIRN II system and how such systems can improve the quality and accessibility of information and referral services.

Background

The NYS Office of Advocate for the Disabled has provided information and referral services via an 800 number since its inception in November of 1978. Like most other human service agencies, staff relied on manuals, brochures and other written material as the basis for the information provided. This was a cumbersome process as information became outdated and there was no formal mechanism to update material. Further, as the volume of calls on the 800 number's three lines and the four local phone lines continued to increase a means to quickly access information and effectively handle the call became more pressing.

In the early 1980's, through a small grant from the NYS Developmental Disabilities Planning Council, the initial SATIRN program and database of 200 entries was developed for Advocate's Office staff. The database continued to expand. It also occurred to agency staff that the same system would be usefulto other human service agencies.

As the nature of inquiries from constituents became more complex, it became clear that new variables needed to be added to the software program to retrieve accurate information and provide appropriate referral. In 1990, the NYS Health Department's Maternal and Child Health, Early Intervention Unit became interested in SATIRN and provided IDEA Part H funds to expand the database to include early intervention services. The Health Department continued to provide financial support which enabled the Advocate's Office to significantly modify the software program and further expand the database. The Advocate's Office TRAID Project also provided financial support to expand the database to include more information on assistive technology and to finance a maintenance contract for regularly updating the database. The program and database, which is updated quarterly, are provided to over 600 users. The SATIRN II system is considered an on-going work in progress as several other state agencies are interested in expanding the system to better meet the needs of their constituents.

Objective

The objective of an information and referral system is to provide accurate, timely information and referral to appropriate programs and services in a polite, efficient, and cost-effective manner in a format usable by the consumer. The consumers of the Advocate's Office Information and Referral services include people with disabilities, their families, advocates and service providers, units of local and state government, elected officials, small and large businesses and the general public. They are from every region of the state, every race and ethnicity, every socio-economic status, every formal education level, every professional discipline and non-professional occupation, every type of disability and have a myriad of concerns that they need to have addressed.

Therefore, a flexible, comprehensive, user-friendly, responsive system was required to meet these needs. The SATIRN II system sought, and continues to seek to accomplish this goal.

Approach

The first matter to be determined was what information should be put into the computerized database. The monthly data tracking of calls received was used as the vehicle to ascertain topic areas that received the greatest number of inquiries. After staff decided the topics to be included, they worked with a computer programmer to help determine the best mechanism to retrieve information. The four main topics selected for defining search criteria included population groups, services, ages served and geographic regions. Under each main topic there are multiple subcategories. Under "Populations", these include various medical conditions, various disabilities, ethnic/cultural groups, ex-offenders, families, homeless, migrants, parents and veterans. Under "Services", accessibility, ADA, early intervention, education, employment, evaluation/screening, funding, medical provider type, research, support, technology and therapeutic are included. These categories are further subdivided into additional search categories. Age groups are divided into eight categories. Regions are divided into 11 categories which can be further subdivided to access each county of the state or out-of-state entries.

SATIRN II allows up to five criteria to be used when conducting a search. The search may be conducted to look for programs or services which meet all of the criteria selected or one of them. A new search function has been added that allows one to conduct a search by simply knowing the name of a program, service or agency.

All entries in the database complete a questionnaire and each of these entries is updated annually. Users receive updated database information quarterly. The software program is reviewed annually and appropriate changes are made which reflect the feedback of the users.

Discussion

The SATIRN II program and database must not only try to meet the needs of a diversified constituency but also funding sources that may at times have conflicting needs. The Advocate's Office must address the information and referral needs of all people with disabilities, of all ages. The NYS Department of Health's Early Intervention Unit contracts with the Advocate's Office to serve as the Central Directory of Early Intervention Services. The TRAID Project needs the information and referral system to provide comprehensive information on assistive technology.

Other agencies are engaged in discussions with the Advocate's Office to include software program and database changes that will best meet the needs of their constituents. It is, therefore, essential that good communication among funding sources transpire and that the Advocate's Office serve as an information hub and conduit to assure this happens.

Another key factor is updating and maintaining the database. New quality control measures have been instituted to assure that the programs and services in SATIRN II complete the questionnaire accurately and completely.

Whether users access SATIRN II by receiving their own diskette, through a public library or service agency, or through the Advocate's Office Bulletin Board System, the accuracy of the data and the ease of use of the software program are their primary concerns. As a work in progress, SATIRN II will continue to expand and diversify to better meet the needs of people with disabilities in New York State.

References

None

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ANALYSIS OF ABLEDATA INFORMATION REQUESTS: IMPLICATIONS FOR ASSISTIVE TECHNOLOGY INFORMATION DISSEMINATION

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Abstract

ABLEDATA serves as one of the most important national sources of information on assistive technology and manufacturers of products for people with disabilities. In order to continue to serve the needs of current patrons and potential users of ABLEDATA information, ABLEDATA project staff conducted an in-depth analysis of ABLEDATA patron encounters during a one-year period. This paper analyzes the utilization of ABLEDATA by different patron categories, using information obtained from telephone and mail requests to ABLEDATA during the period from November 1, 1992 through November 30, 1993. Data were analyzed by: type of caller; type(s) of information requested; the extent of research involved in information requests by caller category; and the region of the country from which requests came.

Background

ABLEDATA is a major resource of information on products for people with disabilities. ABLEDATA originated as a manual index of manufacturers' catalogs of rehabilitation products, and over the years has been systematized and computerized to provide comprehensive information about products and manufacturers of products for people with disabilities. While the information in ABLEDATA originally was collected and organized primarily as a resource for service providers in the health care service delivery system, today it serves as a primary source of information for a varied constituency, including: consumers and consumer representatives; service providers; advocates; researchers; business people who manufacture or distribute products for people with disabilities; and other categories of patrons.

Research Question

ABLEDATA currently responds to approximately 6,000 information requests per year. The purpose of this research was to identify, categorize and analyze the ABLEDATA patron requests for information. By identifying who is contacting ABLEDATA and what their major information needs are, it will be possible to: 1) develop materials and resources that specifically address the most often-requested information needs; and 2) develop strategies for reaching out to underserved patron categories. The results of this research should have important implications not only for ABLEDATA, but also for other information and referral programs, particularly those that provide assistive technology information.

Method

When Macro International obtained the ABLEDATA contract in February, 1992, a contact form that had been used to collect data previously by the National Rehabilitation Center (NARIC) was modified to include ABLEDATA information request data. A contact form is completed for any patron who contacts ABLEDATA directly, whether that is by telephone, fax, written inquiry, or via an in-person visit to the project. Contact forms are not completed for individuals who contact ABLEDATA through the ABLE INFORM computer bulletin board, nor is the project able to collect data on users of previous versions of ABLEDATA through HyperAbledata or independent computer bulletin boards that utilize the ABLEDATA database.

The data compiled for this paper include all direct patron contacts for whom a client contact form was completed, according to the criteria established in the previous paragraph, for the period of November 1, 1992 through November 30, 1993. Data for May, 1993 are excluded, however, due to corrupted data files for that period. Consequently, the data included in this paper represent a one-year period for the project and are considered by project staff to be representative data of clients served during the contract period to date.

Data are collected on seventeen discrete patron categories. For purposes of analysis, these seventeen categories have been divided into seven broader categories: **Consumers** (persons with disabilities and family members); **Service Providers** (medical professionals, rehabilitation engineers, therapists); **Advocates** (administrators, counselors, educators); **Researchers** (researchers, students, librarians); **Business Persons** (architects, commercial business personnel, and engineers/non-rehab); **Employers**; and **Other** (no category given, or listed as "other").

<u>Results</u>

During the one-year period represented by the data in this study, a total of 5,960 individual requests for information were received. Of these requests, fully one-third (34.2%) were from consumers with disabilities or family members of people with disabilities. Other patron requests included: Service Providers (17.6%); Advocates (16.9%); Researchers (13.4%); Business (6.7%); and Employers (< 1%), with an additional 11% of patrons not identified by patron category (Other).

One of the most important findings of this study was that, although there were significant differences among the various patron categories regarding the kind of information requested, the top category for ALL patron categories was for information about personal care products and devices. Approximately 20 percent of all patrons requested information about personal care products, and this level of requests remained constant across all patron categories.

If personal care products are excluded, the kinds of information requested vary considerably by patron category, with the most significant difference occurring between consumers/family members, and all other categories. Whereas Consumers requested information primarily on personal care products (25.2%), architectural elements (14.4%), and home management products (12.3%), major information requests from other patron categories were considerably different. For example, 17.4% of Service Provider requests were related to therapeutic aids; Advocates requested information on vocational management (9.8%) and computers (9.7%) at approximately the same level of interest as information on architectural elements (9.5%) and home management (9%). The table below provides statistical information about the major categories of information requests by each patron category. Only those categories that generated ten percent or more of all requests within the specified patron category are included, due to space limitations (four categories representing slightly less than ten percent of the Advocate requests are included because they represent the major categories of information requested beyond that of personal care information).

Major Categories of Information Requested by Type of Patron

<u>Consumers</u>	
1. Personal Care	25.2%
2. Architectural Elements	14.4
3. Home Management	12.3
<u>Service Providers</u>	
1. Personal Care	27.6%
2. Therapeutic Aids	17.4

Advocate

1. Personal Care	19.2%
2. Vocational Mgmt	9.8
3. Computers	9.7
4. Architectural Elements	9.5
5. Home Management	9.0

Researchers

1. Personal Care -	20.1%
2. Architectural Elements -	12.7

Business Persons

1. Personal Care -	21.9%
2. Architectural Elements -	14.1
3. Therapeutic Aids -	11.9

The third major focus of the ABLEDATA study was to look at the types of services requested by ABLEDATA patrons. Once again, the needs of consumers differed significantly from the needs of all other categories. While consumers generally requested and received referrals, publications or brochures in response to their information needs; professionals tended to request database searches.

Most patrons received more than one type of service per call or visit. A total of 13,511 services were provided to 5,960 patrons (an average of 2.3 services per patron). Services were provided in the following categories: **Referral** (to appropriate organizations or companies); **Publications** (fact sheets, information packets); **Brochures** (about ABLEDATA and related services); **Searches** (searches of the ABLEDATA database); **Quick Reference** (information readily available to Information Specialists); **General Reference** (reference librarian services); and **Inquiry** (asking about ABLEDATA and the services provided).

Services Requested by Patron Category (Top Three Requests Listed for Each)

Consumer

1. Referral	24.7%
2. Publication(s)	21.6
3. Brochure	20.1

Service Provider

1. Search	33.3%
2. Inquiry	15.0
3. Gen. Reference	14.8

Advocate

1. Search	21.6%
2. Inquiry	19.0
3. Brochure	16.8

Researcher

1. Search	27.2%
2. Brochure	24.3
3. Inquiry	13.1

Business Person

1. Search	33.3%
2. Inquiry	17.9
3. Gen. Reference	17.1

Discussion

ABLEDATA clearly addresses different needs for different people. For people with disabilities and their families, it represents a ready source of information about where to obtain specific products to meet everyday needs, and for brochures and other written information. For service providers, database searches are one of the most-used services. The sheer volume of information requests received, however, and the varied uses for that information underscore the importance of maintaining up-to-date information on products for people with disabilities.

References

ABLEDATA project statistical data, November 1, 1992 through November 30, 1993.

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INTERDISCIPLINARY, MULTILEVEL TRAINING IN ASSISTIVE TECHNOLOGY

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ABSTRACT

The development and implementation of an interdisciplinary training program for graduate students, working professionals, and consumers at the University of Washington is described. The program includes a core sequence of courses for graduate students from a variety of disciplines, continuing professional education courses and workshops, and consumer training and consultation. Consumers also participate in both graduate and professional training.

BACKGROUND

A significant gap has been noted between the development of assistive technology (AT) and the implementation of solutions using assistive technology to the educational, vocational and independent living needs of individuals with disabilities in community-based settings. This discrepancy between technology development and implementation has been ascribed to deficits in awareness of technology-based solutions among working professionals, deficits in knowledge of consumers seeking technology-based solutions, parochial professional and agency practice boundaries which disrupt the interdisciplinary, multi-agency approach necessary to implement assistive technology solutions, and importantly, barriers encountered due to funding. At the University of Washington, several courses in AT were offered by the Departments of Rehabilitation Medicine, Special Education, and Speech and Hearing Sciences. In addition, clinical AT services were offered in several locations throughout the teaching hospital system. In one of the courses, Augmentative Communications taught by Dr. Nola Marriner, consumers had long been included as members of the graduate course, and both consumers and graduate students applauded this effort. The lack of integration and cross-disciplinary training was of great concern to faculty and funding to initiate an interdisciplinary program was sought.

OBJECTIVE

The goal of the University of Washington Assistive Technology Training Program was to develop an integrated approach to training pre-service and working professionals and consumers and their representatives/families. We sought vertical integration of consumers throughout the program. Five objectives were defined:

(1) <u>Pre-service, undergraduate occupational therapy</u>
(2) <u>Interdisciplinary graduate core of AT courses</u>
(3) <u>Variety of professional and continuing education courses in different formats</u>
(4) <u>Vertically integrated consumer and family member participation, training, and consultation</u>
(5) <u>Development of an AT Resource and Consultation Center</u>

APPROACH

We sought and received funding from Health and Human Services Administration on Developmental Disability for an Assistive Technology Training Initiative (funded to the Child Development and Mental Retardation Center's University Affiliated Program (UAP)), the Department of Education National Institute On Disability and Rehabilitation Research (NIDRR) for a Careers in Assistive Technology Training Project (funded to the Department of Rehabilitation Medicine), and from NIDRR for the Statewide AT Project funded through the Washington Division of Vocational Rehabilitation to the UAP

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Statewide AT Resource Center and Training Project.

At the undergraduate level, OT faculty infused the entire curriculum with AT and added a required, designated course on AT. Laboratory assignments were included with extensive, *hands-on* practice.

At the graduate level, a core of six courses were developed, including Augmentative and Alternative Communications, Technology in Rehabilitation and Education, Human Factors, Environmental Design and Service System Interface for AT, Customizing Access to Technology, Specialized Applications in AT. These courses have been revised and reconfigured several times in response to faculty and student input. Community-based field experience and practica are included in each course. This AT core serves students from Speech and Hearing Sciences, Special Education, Social Work, Occupational Therapy, Physical Therapy, Rehabilitation Medicine, and in the future potentially, Architecture and Urban Design, Business, Engineering, Computer Science and Psychology. Stipend and tuition support has been available through the NIDRR-funded Careers in Technology grant. Graduate students define their AT focus by adding the AT core to their discipline-specific program of studies, usually filling the elective requirement. For those students in a thesis track, we recommend that the focus of their thesis or project be AT and that a core faculty member sit on their committee. In addition to matriculated graduate students, working professionals from rehabilitation counseling, special education, and speech pathology have participated in courses, as have post-doctoral fellows participating in the University Affiliated Program, and consumers and their family members.

For the continuing education component, we have widely advertised the on-campus courses and offered the courses in compressed formats, late in the afternoon, and on an audit basis. In addition, we have sponsored two and three week AT Summer Institutes and will be offering a one week Introductory Summer Institute this coming summer. We will also experiment with adding a distance learning component to the Augmentative Communication course this spring.

Consumers and their representatives have participated in all aspects of our training. In addition to the training described above, students are required to work with consumers in the community, and we have provided focused consumer training, included a highly successful series of miniconsultations at the Washington Technology Alliance Conference in Spring, 1993. These miniconsultations, conducted by grant faculty and students in the round, afforded families and professionals the opportunity to observe and participate in miniconsultations designed to assist consumers in identifying appropriate questions to address when they surveyed the vendor and program exhibits.

The Assistive Technology Resource and Consultation Center is evolving as the Statewide AT grant gets underway and will integrate resources already available throughout the University of Washington with those of Services for the Blind and other community-based networks. The Center includes policy and funding analysis and information and referral as well.

APPROACH

It would have been extraordinarily difficult to mount the U.W. AT Training Project without external funding. We have encountered a set of barriers to program development and integration that parallel the barriers consumers encounter seeking AT services and devices. The difficulties transiting university and community-based systems are significant and require ongoing vigilance to ensure effective and meaningful consumer and community involvement. Our approach to vertical integration of consumers and professionals in AT Training has been well received by participants and well reviewed by program faculty.

ACKNOWLEDGMENTS

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Interdisciplinary AT Training

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Use of Multiple Parallel Interface Strategies to Create a Seamless Accessible Interface for Next-Generation Information Systems

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Abstract

The next generation of information system is rapidly moving toward touchscreens or pointing devices combined with graphic displays. While these interfaces make the information systems much friendlier for individuals with cognitive disabilities as well as for the general population, they pose significant new barriers for individuals with physical, visual, and, if sound is involved, hearing impairments. Special access software can be used to provide access to personal computers. When these information systems show up in public places, community centers, libraries, etc., however, it is not possible to install individual software to meet individual needs. To provide access to these information systems, a seamless adaptable human interface protocol is proposed which allows users to incrementally modify the command and presentation aspects of the human interface to match their abilities and preferences. A first implementation of the protocol is presented.

Statement of the Problem

The basic objective is to create an interface protocol, including command and control structures, which would support multiple control strategies (mouse, keyboard, touchscreen) and presentation forms (standard graphic, large print, voice) simultaneously. In this fashion, users could mix or match any and all of the control and presentation formats in order to best accommodate their individual needs. While a strictly hierarchical branching structure would achieve this, it also made operation of the system rigid and unnatural. This would cause the system to be unacceptable to commercial parties as a standard interface on mass market products. Thus, the structure also had to be able to support flexibility and a free flow.

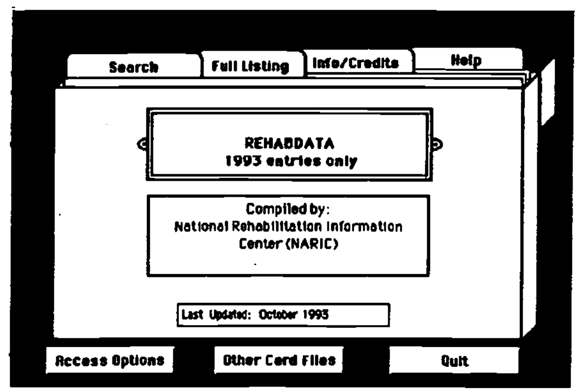
Approach

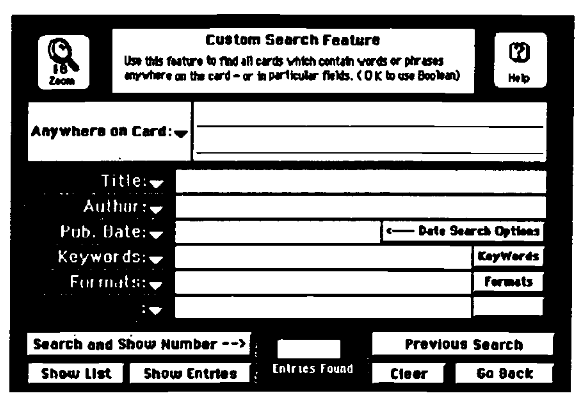
A modified multi-level object-based hierarchy was therefore used. With this structure, the current objects on screen form a context. Using a Tab key or the Control key combined with a letter key, the individual can move around amongst the objects (buttons, fields, etc.) or groups of objects (e.g., a grouping of related buttons). The Space bar and Enter key are used to act on the objects. The Space bar would be used to press buttons and to mark things in a list; the Enter key would function to activate the default button or achieve the same effect as a double-click, depending upon context. Arrow keys would be used to move about within fields. If the voice mode is turned on, the Alt and Control keys can be used with the arrow keys to cause the system to read a letter, word, sentence, paragraph, or the entire text fields, moving either forward or backward.

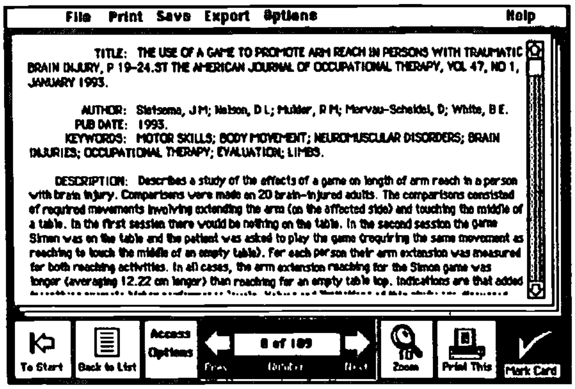
The output options include either standard graphic display, graphic display with larger print in fields where the information changes, voice output, and a large print mode which supports fonts up to 72 point.

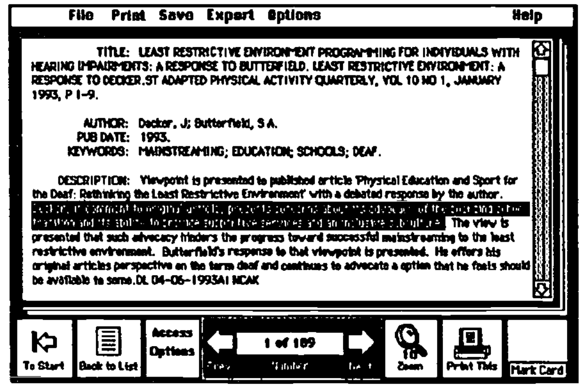
The PMM Database Implementation

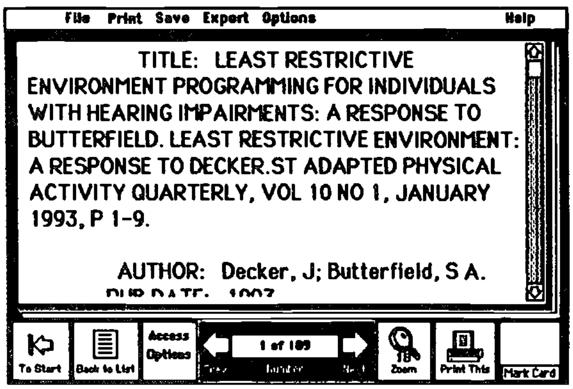
The first implementation of the protocol is in a bibliographic database software package titled Publications, Media and Materials (PMM). This is a software package which was developed for the Trace Cooperative Electronic Library. The software is compatible with any ProCite or ProCite-compatible bibliographic software (such as EndNote). Figures 1, 2, and 3 show standard graphic screens from the database. The database can be operated using a mouse or can be operated entirely from the keyboard.











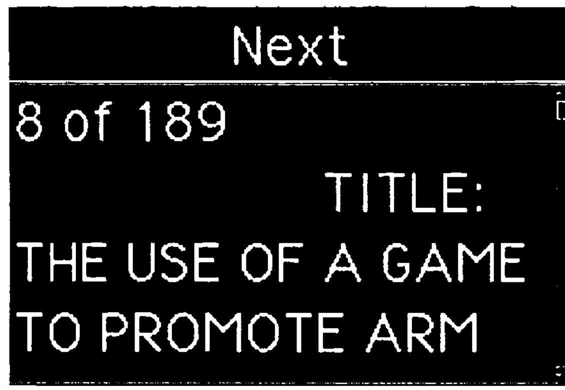


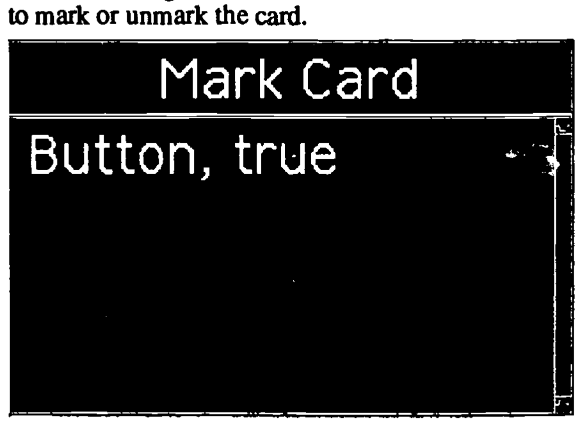
Figure 4 shows the ability of the database to enlarge the text in the data field. For some users, it is unnecessary to enlarge buttons and other controls, since once they have used the database for a short time they can recognize and use the controls without having to enlarge them and use up valuable display space on the screen. However, they need to have the text in the actual data fields enlarged so that they can easily read it.

Figure 5 shows the database in its voice output mode. Using the arrow keys in combination with the Alt and Control keys, the individual is able to highlight letters, words, phrases, sentences, paragraphs, etc., and simultaneously have them read aloud. Similarly, as the individual uses the Tab (or Command-Letter) key to move about on the buttons and fields, the voice output option would read the name of the field or button, along with its state (on, off, etc.). Using the keyboard control mode and this voice output capability, it is possible for individuals who are completely blind to operate the database.

Figure 6 shows the database in its large print mode. In this mode, all of the information is presented in two large fields which can be adjusted in size and font. Their can be adjusted to fill the entire screen, and can present up to a 72-point font.

The top field gives the name of the object (the field, button, screen, etc.). The bottom scrolling field is used to present additional information about the object (e.g., whether a button is on or off) as well as the contents of any field selected. In Figure 6, the individual has tabbed up to the main data field, which is called "Card Text." The text of the field appears in the bottom large print field.

In Figure 7, the individual has tabbed to the button which appears in the bottom right-hand corner of the screen in the normal text mode. This is a button that is used to mark or unmark a particular entry. In this case, you can see from the field that the button is currently turned off. Hitting the Space bar would toggle the button on and off in the large print mode in the same way that hitting the Space bar would toggle the checkmark on and off if the individual had tabbed to the "Mark Card" button (or had used Control-M to jump there). Individuals who were using a mouse would click on the button to mark or unmark the card.



This large print mode has a number of advantages for individuals with severe visual impairments. First, it presents all of the critical information in a very large, high-contrast san serif font. Second, it uses an iso-location strategy for presenting the information to the user; that is, the information is always presented in the same location on the screen. As the individual with low vision "tabs around" the screen, they do not have to keep searching the screen to try to find out where they are. The information about their location is always presented at the top center of the screen. They also do not have to worry about missing particular buttons or features. By successively hitting the Tab key, each and every button or field on the screen will be presented to them. Once they are familiar with the contents and buttons on the screen, they can jump directly to the items they are interested in by using the Control key along with the first letter of the object (button, field, etc.). If more than one object starts with the same letter, they would simply continue to hold the contro lkey down and hit the letter again until the desired object came up. They can also type multiple letters to instantly call up any item if it shares a common first letter with other objects.

Strategies to Increase Efficiency of Access

In addition to the basic strategies which in themselves provide complete access, there are a number of additional strategies which are incorporated to allow individuals with disabilities to have more efficient access. Whenever an individual is in a list, typing the first letter or letters of an item in the list will cause the highlight to jump to the line or item that begins with those letter(s). The Control-letter function provides a similar jump capability to any object on the screen. In both cases, a minimum-to-distinguish strategy is used which allows the individual to type multiple letters in order to jump directly to the desired item.

In addition, when operating in either the voice output or large print mode, additional context information is provided with some actions. For example, the "Next" arrow button is used to move through the different card entries. Normally, in the large print the individual would tab to the "Next" button and then activate it. They would then have to tab up to the card text field in order to see the title of that next item. In actuality, however, when using the "Next" button in the large print mode, the title of the next entry is automatically displayed in the bottom field along with the count. As a result, the individual can sit on the "Next" button and successively activate it. Each time they do, the bottom field will display the number of the new entry and its title. The individual can then simply use the arrow keys to begin reading any entries of interest.

Conclusion

Although this implementation only demonstrates the technique on a single database, it does provide an interesting opportunity to study the technique while simultaneously providing broad-based consumer access to the Publications, Media and Materials (PMM) database on the Co-Net CD. The technique is now being expanded and implemented on other databases. In addition, its use with touchscreen-based information systems is being explored.

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User Type/ Characteristics	**Features**
All users	• Operable using mouse, touchscreen, or from the keyboard, at user option. • Friendly, easy to understand graphical interface. • Ability to have sounds visually depicted for noisy environments or no-sound environments (e.g., libraries). • Zoom data text for easy reading.
Users with... ...manipulation difficulties	• Ability to operate entirely from keyboard. • Print to paper or print to disk.
...somewhat low vision	• Ability to zoom data text, with fonts from 12 point to 48 point. • Operable from keyboard if mouse is difficult to see.
...low vision	• Keyboard operation. • Full-screen large print mode (up to 72 point). • Single focus point information display feature within the large print mode. • Voice output mode.
...blindness	• Operable completely from keyboard. • Full voice feedback mode (does not require screen reading software).
...cognitive/ language impairments	• Easier to understand graphic interface. • Touchscreen capable. • Voice output mode.
...hearing impairments	• Option for all auditory information to be presented visually.

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Gerontology

Use of Technology to Improve Service to Older Adults: A Computerized Community Care Coordination Network

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ABSTRACT

Many older adults have chronic health conditions that place them at high risk for developing functional impairments and disabilities. Provision of interventions such as assistive technology or community health and social services could be beneficial to these individuals to minimize the effects of these conditions on daily living. Computerized information regarding a change of status or an occurrance of a critical 'event' (e.g., an emergency room visit) that is readily available and frequently monitored could allow follow-up and earlier intervention. A longitudinal computerized tracking system is currently being evaluated with 1000 individuals with chronic health conditions to determine the effects of the availability of information, as well as an 'alert' regarding a critical event, on outcomes such as number and length of hospitalizations, number of emergency room visits, life satisfaction and caregiver burden.

BACKGROUND

'Disability' has been expressed as a gap between an individual's functional capabilities and the demands of his or her environment, for example at work, at home, or in social settings. One framework describing the progression of a disability has been presented by Nagi.[1,2] This framework includes four distinct phases: pathology, impairment, functional limitation and disability. While pathology and impairment describe some abnormality at the cellular or organ level, it is not until the functional limitation stage that performance of daily activities is affected. When a functional limitation affects performance in a socially defined context or role (e.g., working), then it is classified as a disability. A disproportionate number of older adults are reported to have disabilities.[3]

While disability is not *synonymous* with aging, the high prevalence among older adults of chronic conditions such as diabetes or arthritis places these individuals at high risk for developing functional impairments and disabilities. In fact, some researchers suggest that the presence of a chronic condition may be the most important perspective from which to consider the development of impairment, functional limitation, and possibility disability.[4] Many interventions, including the provision of assistive technology or social services, could reduce the risk that an impairment or a functional limitation becomes a disability. Unfortunately, while primary care providers are able to monitor disease, they have no systematic means to monitor the emergence of functional impairment or disability. Often, little is done in the way of secondary or tertiary interventions for those with chronic conditions until a severe functional limitation or disability has evolved. The use of technology to track individuals with chronic conditions longitudinally along such factors as cognition, functional status, physical and occupational therapy needs, home environment, assistive devices used, and major 'events' such as an emergency room visit, could allow earlier intervention and perhaps prevent more severe functional limitation and/or disability.

While technology has been developed that would facilitate longitudinal tracking of these individuals to record changes in functional ability, services received and quality of life, this information typically is not readily available to service providers.

In addition, a lack of coordination of information and services between primary care providers, emergency rooms, and social service agencies could also contribute to the problem. A computerized tracking system that links these three together and makes this information available to all health and service providers could provide a viable tool for proactively addressing individuals at the impairment stage. Interventions provided here could prevent them from progressing to the functional limitation or disability stages. For example, a visit to the emergency room for a wrist fracture could be tracked, and the computerized system could 'flag' the attention of a primary care provider. This professional could follow up to determine whether the individual might require the use of an assistive device such as a pan stabilizer (to allow one-handed stirring) or a service such as Meals on Wheels to ensure adequate meal preparation.

STATEMENT OF PROBLEM

Intervention for individuals with chronic conditions -- often older adults -- frequently occurs once functional limitations or even disability is evident. Availability of information, earlier targeting of 'high risk' individuals, and better coordination of services, could help to reduce, halt or even reverse the progression of functional decline and disability. However, the use of a sophisticated computer tracking system as an intervention tool to provide important information, coordinate services and identify individuals in need of follow-up, to date, has not been evaluated.

APPROACH

A computerized clinical data management system is in place at the Reynolds Health Center (RHC), a large community health center in Winston-Salem, NC, and contains information on over 52,000 patients. Information in the database is 'relational' in nature, allowing multiple versions of the same variables to be saved at successive times. For example, the database can retain several records of functional status measured as an individual recovers from hip replacement surgery, thus providing a useful chronology for the health care provider.

While this type of information typically does not affect primary care physicians decisions,[5] it may be useful in improving patient outcomes when made available to community service providers (e.g., home health nurses).[6] Furthermore, if this information is made accessible to emergency room staff, this could potentially reduce the number of hospital admissions if the emergency room staff is confident of adequate follow-up community care.[7] For example, a social worker who sees an older individual in the emergency room may discover a record of multiple falls through information available in the tracking system. This social worker may then recommend a home environment or assistive technology evaluation by a physical therapist, occupational therapist, or rehabilitation engineer to prevent future occurrances and reduce the risk of further functional decline.

A project is currently underway to expand the existing tracking system to include two area emergency rooms and community service providers. RHC patients will be screened for the presence of one of several chronic conditions (e.g., diabetes, arthritis), and one thousand individuals who have difficulties performing one or more ADLs or three or more IADLs will be recruited for participation. The evaluation will use a 2 x 2 factorial design (entry/no entry in tracking system x alert/no alert of primary care provider after an 'event'). Individuals will be randomly placed into one of four groups: database tracking only, primary care physician alert only, database/alert or control. Individuals will be 'tracked' for two years, and objective measures will be recorded such as number of emergency room visits, hospital readmissions, length of stay in hospital, as well as subjective measures such as life satisfaction and perceived caregiver burden. These variables will be compared across groups to determine if the availability of this information in a computerized relational database and/or the presence of an alert for follow-up, affect these treatment outcomes.

IMPLICATIONS

The project aims to demonstrate that the use of technology (in the form of a computerized tracking and alert system) can link services of primary care providers, community and social services personnel, and hospital emergency staff. It is anticipated that this coordination and longitudinal tracking will identify individuals (based on specific health care 'events' targeted in the system) who could benefit from follow-up services (e.g., provision of assistive technology, evaluation of the home environment, personal assistance). The goal of these interventions is to reduce the rates of unmet service needs, emergency room use, hospital admissions and caregiver burden, and potentially prevent or delay the progression of further functional limitation and disability.

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DIFFICULTIES AND DEPENDENCE IN BATHING: INTERVIEWS WITH BATHERS AND CARE-PROVIDERS

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Abstract

This paper is based on a study that interviewed bathers and their care-providers. It examines the bathing difficulties experienced by these people and discusses what triggers people to seek bathing assistance. More specifically, the paper addresses the following questions: What type of bathing difficulties do older people and their care-providers experience? What causes these difficulties? What necessitates people to seek bathing assistance? What establishes bathing dependence? The paper discusses the interconnectedness between bathing difficulties and bathing dependence, and it concludes with a vision of a universal bathing unit that will not only make bathing safer, but will enhance privacy and extend independence for some people.

Background

Bathing is the most private of all everyday activities. In addition to health concerns, the fundamental purposes of bathing are to maintain a socially acceptable appearance, and for refreshing, reviving and relaxing. When unable to bathe independently, a person's physical and psychological well being are seriously effected. This is because using the bathroom is the last bastion of self reliance and is linked with privacy, dignity and self-worth. Also, the ability to bathe independently is grounded in our history, culture and social values.

Bathing difficulties escalate sharply with advanced age and varies greatly between the late middle aged (55-64) and the elderly. Not all people experience the same type of difficulties; some have problems getting in and out of the bathtub, while others have difficulty adjusting the flow and temperature of water. Bathing difficulties are also due to poor design of bathing fixtures and bad layout of existing bathrooms. Historically, the development of bathing equipment has been more of a chance than conscious design. The earliest known bathtub dates back to the Minoan dynasty in 1700 B.C. Interestingly, bathtubs today have remained virtually unchanged and they still resemble the Minoan tub. The design of twentieth century bathtubs and showers have unknowingly excluded many users, except those who are able-bodied. Consequently, they pose great danger for the elderly, people with disabilities and children.[1,2,3]

Assistance in bathing is viewed as an encroachment into privacy, and people, therefore, avoid or delay asking for it. Today's small 5'X8' bathrooms are for one-person use, and they reflect the modern values toward privacy. Yet people living in their senior years require assistance. The absence of suitable care-oriented bathrooms not only makes assisting people acutely stressful,[4] but also makes older people hesitant about accepting assistance in the bathroom, even if it threatens their physical well being. Despite of being frail and needy, they often reject bathroom care from individuals of the same or opposite sex. Small bathroom size complicates the task of caregivers, who often are fatigued and injured assisting others.[5, 6]

Research Focus

The primary purpose of this study was to generate qualitative data necessary for designing a universal bathing unit for use by all people, including the elderly. Extensive research was aimed at assessing the bathing needs of older persons living at home and their care-providers. This research uncovered a number of issues including bathing difficulties and bathing dependence. The universal bathing unit is expected to be easy to use, offer greater safety and more independence for all users. For older people, it is expected to prolong bathing independence and encourage longer self-reliance at home.

Method

The field research was based solely on three categories of interviews: focus group interviews with four to seven participants, personal interviews with bathers, and joint interviews with dependent bathers and their care-providers. All together 40 participants were interviewed for the study: 20 independent bathers (those who bathe on their own), 6 dependent bathers (those who are bathed by another individual), 3 family care-providers (persons who bathe their relatives/friends) and 11 homecare-providers (professionals who bathe clients). All of the bathers live in non-institutional settings, most of them in apartments, some in their own homes, and a few in housing projects for senior citizens. The care-providers are either family members or they are employed by healthcare agencies. All interviews were audio-taped and the bathrooms of those people interviewed in their homes were video-taped. The videos were later reviewed to determine the environmental conditions of the bathrooms. The content of the interviews were evaluated based on the quality and frequency of responses received. The similarities, differences and uniqueness of the information helped develop a pattern of bathing needs and preferences.

Findings

The study provided qualitative data and insightful information necessary for designing a universal bathing unit. Examples of the type of information obtained include: how people bathe; what type of accessories they use; how bathtubs and showers are maintained; what people like and dislike about their bathing area; the types of problems they experience; what causes stress and fear; what type of safety measures people undertake; and how accidents happen. The bathing difficulties people experience is as follows:

Bathers:
1) The most common problem was maintaining balance when bathing and transferring in and out of the tub. Those unable to make safe transfers had abandoned tub-oriented bathing; 2) Other problems were largely due to inadequate reach, poor grasp and low level of thermal sensitivity; 3) Because of their inability to "reach low," many individuals find it impossible to use controls from the outside of the tub; 4) Opening faucets and adjusting water temperature are troublesome for many; 5) Those who lack sensation in the hands frequently misjudged the water temperature and got scalded; Those with tremor of the hand or arthritis in the hand were unable to fine-tune the temperature and flow adjustments; 7) A majority of persons have difficulty using lever type controls. Even though they felt they were easier to use, the difficulties were due to problems understanding the color-coded signage for water temperature and flow, complex operational demands of the faucets requiring two simultaneous actions, push and turn, or pull and rotate, and non-standard nature of these operations; 8) Accessible showers, specially built to provide a greater degree of convenience, were not free of problems. Several users of accessible showers indicated they had trouble using controls and bathing accessories while sitting on built-in seats. Consequently, many of them were either forced to stand up with water running to reach for accessories, or store them on the seat. One individual had installed a transfer bench and a flexible hose to combat the reaching difficulty. Another individual who has a paralyzed right side, had no use of the grab-bar (since it was located only on the right side). In the absence of a bar on the left side, getting out of the shower safely was difficult. A third person, a lower limb amputee, found it impossible to make transfers to and from the built-in seat. She used a transfer seat to get in and out of the accessible shower, and used the built-in seat to hold accessories; 9) The size of the bathing space presented diametrically opposite problems. Small size restricted movement of wheelchair users and those providing care. Excessively large space made controls and accessories inaccessible, and wheel-chair users became fatigued from wheeling around in an attempt to reach for accessories; 10) Inadequate storage resulted in cluttered bathrooms. This made it impossible to keep the bathing space organized; 11) Restrictive hallways and awkward bathroom layouts obstruct the movement of persons with mobility aids and those in wheelchairs; 12) Low level of illumination made it difficult to see controls and accessories; and 13) In the absence of auxiliary heating, people felt cold while bathing.

Careproviders
1) Practically all care-providers indicated that bathing people is the hardest task for them, and getting people out of tub is the most difficult part of the task; 2) Narrow passages and poor bathroom layouts make it difficult to walk side-by-side with bathers; 3) Sliding glass doors pose great difficulty in transferring people in and out of the tub; 4) Lack of space between tub and adjoining fixtures hinder providing assistance and restricts access to the bather; 5) Unavailability of a proper transferring device compels them to manually handle bathers causing physical and mental exhaustion; 6) Bending over to provide assistance causes excessive postural stress; 7) Slippery floor conditions is hazardous when transferring people in and out of the tub; 8) Inadequate lighting in the bath area makes it difficult for them to detect fallen objects; 9) It is difficult to shower people in a shower stall without becoming drenched; 10) Homecare-providers felt that most clients have great difficulty accepting bathing-oriented assistance from other people. Gaining clients' trust and cooperation in the bathing process is the most difficult part of their job.

Discussion

Bathing difficulties that necessitate dependence on other individuals cut across age and sex. Bathing dependence is due to both the loss of physical capabilities and the poor design of bathroom equipment. Dawson et al. (1987) indicates that about 10 percent of the elderly are dependent in bathing and 6 percent use the help of a care-provider.[7]

Difficulties And Dependence In Bathing

The study indicated that bathing dependence varied greatly between people and their physical conditions. Clearly, the ability to bathe independently did not depend on any one factor. Bathing dependence often resulted from illness and/or injury. No individual was completely dependent on being bathed. They all helped themselves to a degree. Bathing dependence was both physiological and psychological. People's ability to bathe on their own depended on age, severity of disabling condition(s) and their willingness to do so.

People greatly value the need to bathe independently, and when unable to do so, they over-extend their abilities and jeopardize their security and personal well being to preserve their dignity. To maintain bathing independence, many individuals challenge their physical capabilities to access difficult areas, thereby injuring themselves, and in some cases causing further dependence. Many others who are constrained by limited reach and poor grip strength receive injuries from overextending and applying excessive force. Others, with grasping and balance problems, slip and fall trying to maintain a stable position when entering and exiting the bathtub.

Bathing difficulties occur from a mismatch between a person's capabilities and the provisions of the bathing environment. When a bathroom does not meet the person's demands, they become frustrated and feel helpless. This compels them to either seek assistance from care-providers or endanger themselves by struggling alone. For example, when unable to stand while bathing, people sit and bathe. But, because of the inflexible design of bathtubs and showers, sitting and bathing makes accessories and controls out of reach. Similarly, when unable to balance while standing, people have difficulty transferring over the high tub walls. Not able to regulate this wall height, requires people to seek assistance to get in and out of the bathtub. In essence, the majority of this segment of bath users are "disabled" more by the design of the existing bathtubs and showers, than by their own inabilities. This result is an incompatibility between people's changing physical capabilities (less capable during infancy and old age) and the inflexible designs of bathing equipment.

In order for people to maintain bathing independence, it is essential that bathing fixtures respond to the changing needs of users by allowing people to make adjustments. This must form the central basis for the design of the new bathing unit. It must be organic and allow alterations as people's needs and preferences change. The new bathing unit must be universal and accommodate the needs of all users. Like infants and young children, the elderly frequently live with people of different ages, sexes and physical conditions, and the bathroom is shared by all. The universal bathing unit must be "inclusive," adopt a "life time" approach to product development and grow as people age. By allowing users to customize to their situation, this product will reduce bathing difficulties and prolong bathing independence. The universal bathing unit will ensure greater use, more safety, higher privacy, longer independence and enhanced dignity for all users.

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Applicability of Grab Bar Accessibility Standards to Meet the Needs of Older People

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ABSTRACT

This paper reports the findings of a study that evaluated the ability of 66 ambulatory and 50 nonambulatory older people to toilet independently and safely. A repeated measures research design included eight test trials in which participants got on and off a toilet using four different grab bar configurations each at two different toilet seat heights. Each trial was videotaped in order to determine patterns of grab bar use for each toilet height/grab bar configuration. In addition, pre-trial and post-trial interviews were conducted to determine participant preferences and perceived safety. Results of this study indicate that some grab bar configurations that were not code-compliant, were preferred and were used more often than configurations that were designed to meet accessibility standards. These findings raise questions as to whether the ADA Accessibility Guidelines and other accessibility standards enhance independent toileting among older individuals or whether they do, in fact, promote dependence.

BACKGROUND

Difficulty in toileting independently is common among nonambulatory elderly individuals who have difficulty transferring, as well as ambulatory individuals with age-related impairments such as arthritis, who have difficulty sitting and standing. However, despite efforts to mandate accessibility through laws and codes, there is no evidence these standards are applicable to older people. Czaja (1983) and others point out that the provisions of the current ANSI standard (ANSI 117.1-1992) and ADA Guidelines (U.S. ATBCB, 1991) are primarily directed toward the functional capabilities of young and middle aged wheelchair users with good upper body strength. As a consequence, there is concern, particularly in buildings used primarily by older people (e.g. nursing homes and independent living facilities), that accessibility provisions may not adequately compensate for age-related decrements in mobility, strength, and stability that are common among older people. Further, Hiatt (1989) noted, in a presentation at the American Society on Aging, that assistive devices that would likely be responsive to the needs and capabilities of older people, would not meet current accessibility requirements.

RESEARCH QUESTIONS

This study examined the following questions:

1. Do different grab bar configurations account for differences in difficulty and independence in toileting for ambulatory and nonambulatory elderly persons?
2. Are grab bar configurations that are code-compliant appropriate for older individuals?
3. Are there grab bar configurations that are not code-compliant that are more appropriate for older people?

METHOD

A repeated measures design was used to address the research questions. The research design included four tasks: (1) construct a toilet room mockup; (2) conduct pre-trial interviews; (3) complete the test trials; and (4) conduct post-trial interviews.

A full-scale, transportable mockup of a toilet room consisting of two six-foot walls at right angles was constructed. The mockup included accommodations for two toilet seat heights (17 and 19 inches) and four grab bar configurations at two heights (33 and 36 inches), as well as for two videotape cameras to record the test trials. The eight configurations on which participants were tested are described below.

Configuration 1 consisted of two grab bars extending from the wall behind the toilet. Each grab bar was affixed to the wall on either side of a toilet, located 48 inches, on center, from the side wall. Both of the grab bars were hinged near the wall to swing up and out of the way when desired. As a result, participants could use one or both grab bars, and could transfer onto the toilet from the front, or from either side.

Configuration 2, in accordance with ADAAG, consisted of two horizontal grab bars placed perpendicular to each other. However, ADAAG specifications for the location of the two grab bars were reversed. The longer, 44-inch grab bar was placed on the back wall, extending beyond the outside edge of the toilet. The shorter, 20-inch grab bar was positioned beside the toilet.

Configuration 3 met ADAAG specifications. The shorter, grab bar (20 inches) was positioned horizontally on the back wall and centered on a toilet, 18 inches from the side wall. The longer, 44-inch bar was positioned horizontally on the side wall, extending beyond the front of the toilet.

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Grab Bars

Configuration 4 consisted of three grab bars. Two grab bars were positioned horizontally, identical to those in Configuration 2. The third bar was placed at a 45 degree angle on the side wall.. The 48-inch diagonal bar was located 20 inches above the floor and angled up and outward extending 72 inches above the floor and 72 inches from the back wall.

A pre-trial interview collected demographic, cognitive, and medical/physical information for each participant. The test trials consisted of having each participant approach and get on the toilet, stay seated for a few seconds, and get off the toilet. Each trial was videotaped from the side by a tripod mounted camera and from overhead by a camera mounted on the test unit. Post-trial interviews consisted of a series of questions related to safety, ease of use, and the helpfulness of the grab bars. After participants had completed all eight trials, they were given photographs of each configuration and asked to rank order the configurations for safety, ease of use, and personal preference.

RESULTS

Sample. One hundred and sixteen individuals 60+ years old participated in the study. Sixty-six (56.9%) of the participants were ambulatory and 50 (43.1%) were nonambulatory wheelchair users. The ambulatory group was almost equally divided between males (n=34 or 51.5%) and females (n=32 or 48.5%). In the nonambulatory group, there was a 3:1 ratio of males (n=38 or 76%) to females (n=12 or 24%). This is a result of the largely male population at the three VA nursing homes (Atlanta VAMC, Decatur, GA; C.J. Zablocki VAMC, Milwaukee, WI; and Audie L. Murphy VA Hospital, San Antonio, TX)which were the source for the majority of the nonambulatory participants.

Self Report Data. The nonambulatory group consistently rated Configuration 1 higher than any of the other configurations, with more than twice as many participants preferring that configuration over the second rated configuration (Configuration 4). This was found for each category, including *safest* (54.8%), *easiest* (58.5%), and *best* (61.9%). In contrast, this group consistently rated Configuration 2 as *least safe* (45.7%) and *most difficult* (50.0%) to use. The ambulatory group also rated Configuration 1 as *safest* (45.8%) and *easiest* (46.6%) to use, and Configuration 2 as the *least safe* 57.4%) and *most difficult* (58.0%). However, the ratings of ambulatory participants for safety and ease of use were bimodal, split almost equally between Configuration 1 and Configuration 4. In fact, 57 percent of the ambulatory group rated Configuration 4 as the *best*, compared to 31.6 percent who preferred Configuration 1. The code-compliant configuration, Configuration 3, ranked no higher than third in safety, ease, and preference.

Observational Data. Videotape data was used to determine: (1) attempted transfers, (2) transfer time, (3) transfer difficulty, and (4) grab bar use.

1. Attempted Transfer. The rate of refusal for nonambulatory participants (20%) was significantly higher than for ambulatory participants (1.1%). There were fewer refusals for Configuration 1 (3.8%) than for any of the other configurations. The primary reason cited for refusing to attempt a test trial was that the participant felt that a configuration was too difficult or unsafe.

2. Transfer Time. Transfer time, the amount of time each participant took to transfer on or off the toilet, was captured in real time by the internal clock in the video recorder. Although there were no significant differences between the configurations within the experimental groups, the mean times for transferring onto and off the toilet, as expected, were significantly higher for the nonambulatory group across all configurations. Overall, mean times for getting off the toilet took considerably less time than getting on the toilet for both groups, ranging from 2.21-2.57 seconds for ambulatory participants and 12.83-14.61 seconds for nonambulatory participants. Mean times for getting on the toilet ranged from 3.78-4.87 seconds for the ambulatory group and from 15.88-20.65 seconds for the nonambulatory group.

3. Level of Difficulty. Transfer difficulty was rated by coders on a 5-point Likert scale from 1 (very easy); to 5 (very difficult). Although there were no significant differences either within or between experimental groups, trends indicate that all configurations were more difficult for the nonambulatory sample, ranging from mean difficulty ratings of 2.9 - 3.25, compared to ratings ranging from 1.27 - 1.34 for the ambulatory group.

4. Grab Bar Use. Grab bars in Configuration 1 were used more often, accounting for almost 40 percent of all grab bar uses (551 out of 1381). In contrast, there were no significant differences in frequency of use among the other three configurations. The grab bars in Configuration 1 were used most often by nonambulatory participants, accounting for 37.8 percent (n=170) of all uses by that group to transfer on, and 42.3 percent (n=156) to transfer off. In fact, the grab bars in Configuration 1 were used twice as often to transfer on as the grab bars in code-compliant Configuration 3 (n=85), and 2.5 times as often to transfer off (156 compared to 65 uses). The grab bars in Configuration 1 were also used most often by the ambulatory group, accounting for 42.7 percent (n=127) of uses to transfer off and 37.1 percent (n=98) to transfer on.

Grab Bars

Side Bar Use. For the nonambulatory group, each of the side grab bars in Configuration 1 was used significantly more often than any other grab bar, although there was no significant difference between the use of the left (20.5%) and right (22.0%) grab bars. Moreover, there were no significant differences in the use of any of the individual side bars in the other three configurations. However, when use of the diagonal and horizontal bars on the same side of Configuration 4 are combined, use of the side bars in this configuration (23.5%) was significantly greater than the use of the horizontal bars in either Configuration 2 or 3.

For the ambulatory group there was a significant difference across configurations in use of side grab bars. However, this difference can be accounted for by the virtual non-use of the short horizontal side bar in Configuration 4. The other grab bars were used with almost equal frequency for transfer on (8.5% to 10.8%) and off (9.47% to 12.3%). In fact, if the use of the short bar and diagonal bar are combined, there is no statistical difference among the four configurations for the ambulatory group.

Rear Bar Use. The frequency of use of rear grab bars was minimal for the nonambulatory group (n=70) and virtually nonexistent for the ambulatory group (n=10). There were no significant differences in the use of rear grab bars by ambulatory participants as there were no more than two uses for any of the three configurations. However, the significant within group differences in the nonambulatory group were attributable to Configuration 2, which accounted for 60% of the 70 rear bar uses by nonambulatory participants.

DISCUSSION

Older people who use wheelchairs had much more difficulty in, and required a significantly longer amount of time getting on and off the toilet than did ambulatory older people. These data clearly indicate that grab bar configurations that facilitate transfer and promote independence for nonambulatory older adults are extremely important. Interestingly, grab bars that were the most radical departure from the accessibility standards (i.e., the side bars in Configuration 1 and the diagonal side bar in Configuration 4), were preferred, had much higher frequencies of grab bar use, and fewer refused attempts by nonambulatory participants than did the two configurations that complied with, or only minimally departed from current accessibility standards. In contrast, ambulatory participants used all of the side bars with statistically equivalent frequencies, thus indicating that none of the alternatives was any more useful than another.

In addition, the utility of rear grab bars is questionable. The use of rear grab bars by ambulatory participants was virtually nonexistent for all configurations. Although the use of rear bars was somewhat greater among the nonambulatory participants, the frequency of rear grab bar use was significantly lower than that of side bar use (8.5%) in all three configurations in which rear grab bars were provided. Most significantly, the rear bar that complied with the accessibility standards, (i.e., Configuration 3) had the lowest frequency of use by nonambulatory participants of the three configurations with rear grab bars.

The self report and observational data clearly indicate that grab bars that do not comply with accessibility codes are at least as effective for ambulatory, and, in both Configurations 1 and 4, were more useful for nonambulatory older adults. However, the grab bars in Configuration 1 are most effective when there is sufficient space to approach the toilet from either side. Alternatively, when there is not sufficient space, the addition of a diagonal bar to complement a horizontal side bar, as in Configuration 4, appears to be an effective modification to the current accessibility standards.

The results of this study provides important evidence that accessibility standards do not meet the needs of older individuals. This is particularly important in the design of facilities that will be used primarily by older individuals, such as nursing homes and senior centers, where the law mandates one thing, but where individual needs require something different. In fact, it is possible that grab bars designed to meet the accessibility codes might decrease rather than increase an older person's independence.

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Opportunities for High Technology R&D to Fulfill Needs of the Elderly

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Abstract

Although many of the needs of the older segment of the population could be met by better access to existing assistive devices, there is a definite role for new advanced technology. This paper examines the range of needs of the elderly and proposes combinations of emerging and present technologies as solutions for selected age-related sensory, motor, communication, cognitive and/or social deficits. This exercise is intended as a guide for future research and development efforts, as well as a focus for the attention of RESNA members interested in gerontology.

Population to be Served

Older persons represent a very heterogeneous segment of our population. While 90% or more of those aged 65 and older face little or no impairment, the remaining 8% to 10% have impairments that impact upon their ability to complete daily life tasks. Affected individuals have one or more sensory, physical or cognitive disabilities. The types of assistive devices they need and use are determined by a number of factors, including the type(s) of impairments, presence of a caregiver, and a range of demographic and psycho-social factors.

Conventional and "High" Technologies

Any discussion of assistive technology for the elderly is necessarily dominated by the two major complaints about existing technology:

The required assistive device is unavailable because (a) it is too costly, or (b) care providers or users are unaware of its existence. Regulatory (government or insurance) impediments may also exist, but these usually derive from cost constraints or ignorance. Among the developing strategies to overcome these barriers are new distribution methods that bypass the "medical model" and design for cost-reduction

The required assistive device is unusable because (a) its instructions are unclear, (b) it has been incorrectly prescribed and/or adjusted for the individual user, or (c) it is poorly designed. Frustration with devices that do not work the way they should is a primary cause of non-use; of 157 elders who owned an average of 13.7 assistive devices, only 79% of aids were actually used, and only 72% resulted in satisfactory performance [W. Mann, UB-RERC on Aging Consumer Assessments Study]. Typical devices that frequently fall into this category are canes, walkers, bathing aids and telephones.

Other assistive devices based on conventional technology that often suffer from both complaints are

- Seating and mobility aids (wheelchairs, walkers, "geri" chairs, shoes, etc.)
- Bathing aids (bathtub seats and benches, grab bars, accessories)
- Vision aids (eyeglasses, lighting, magnifiers and telescopes)

Improvements could be made to these commonly available items by incorporating "high technology" materials and electronics. Examples include wheelchair and walker frames made of composites instead of steel tubing, grab bars with non-slip textured coatings, and lighting fixtures with contact or sound-activated switches.

"High" technology may be defined as the manufacture of products based on recent advances in understanding of materials and information processing at the microstructural level. Incorporation of high technology is not necessarily perceptible to the user; in the case of materials, the only evident difference between conventional and new technologies may be in lighter weight or reduced breakage. In electronic devices, technological advances should result in more function in smaller packages with reduced power consumption. Initial introduction of new technology may be accompanied by higher unit cost, but over time the cost should drop below that of equivalent devices made using older methods (if not, the cost may be artificially inflated for reasons other than technological).

At the macroscopic level of the human interface, the real contribution of high technology is often overshadowed by a "high tech" appearance caused by either deliberate or inadvertent design and marketing decisions. Poorly designed "high tech" apparatus may require too much attention and control input from the user; if the human interface is well designed, it will reduce the sensory and manipulation burden on the user, rather than add to it. The goal of reducing burdens imposed by disability should apply to devices to assist the care-giver as well as the recipient of care.

In addition to physical considerations, device design should take into account psychological factors: many seniors are intimidated by "complicated" technology. "High tech" devices may employ complex internal functions, but they should not be "complicated" for the user to operate. Video recorders and remote controls are examples of complex devices with "complicated" controls that require high motivation to learn to use effectively. Automatic bread bakers are as sophisticated internally and touch-tone telephones connect to much more complex decision-making networks, but have simple human interfaces and are therefore more readily accepted (note that the telephone was also cited above as frequently unsuitably designed for some users' needs; both statements are true).

Categories of diagnostic, therapeutic and self-care needs

One of many possible groupings of needs into categories is as follows:

Life-fulfillment/continued productivity with disability
- Communication - voice, nonverbal
- Computers and electronic mail adapted for elderly users

Mobility
- Adaptation to changing ambulation capabilities
- Balance assessment, therapy, fall injury prevention
- Fall detection and warning
- Navigation -individualized local maps
  - Talking exit and directional signs

Manipulation
- Reachers with tactile feedback or force amplification
- Dressing aids

Sensory aids - hearing, vision, balance and proprioception, smell ,taste
- Audible color matching of clothing
- "Eyeglasses" that compensate for missing areas of retina

Aids for caregivers/providers
- Geriatric assessment: lifestyle, social, environment, psychophysical
- Rapid communication between caregiver and recipient (*i.e.*: nurse call)
- Devices for repositioning or turning in bed
- Keys or keyword commands for ovens, stoves, other hazardous appliances

Aids for severe or combined progressive deficits
- Memory aids and stimulators - e.g.: step-by-step prompting/cueing of ADLs
- Urinary and bowel continence training aids

Under these six broad categories, which are obviously not mutually exclusive, are given suggestions for specific needs or projects. These suggestions were selected as being problems difficult or impossible to address without application of one or more new technologies. Note that this categorization omits advanced medical technologies, such as implantable prostheses or functional electrical stimulation; although applicable to some needs, these are generally considered to be outside the realm of rehabilitation practice.

High Technology on the Near Horizon

"High" technology does not automatically imply prolonged expensive research to place into effect. Most often high technologies such as embedded microprocessors, feedback control, digital signal processing, chemical or physical sensors, and advanced materials will be combined with older technologies that form the bulk of the actual device. Recently introduced devices that may be useful (perhaps after redesign or adaptation) include medication timers, wireless pagers, intercoms, and remote controls for audio and video equipment. At least two classes of technology are being phased into service to meet general needs, and will be relatively simple to adapt to the needs of the elderly:

- "Smart house" technology (*e.g.*: environmental controls) for individuals, nursing homes
- Voice commands, (later) speech recognition for control, communication

As an example of near-term application of a "high" technology hitherto untried for solving problems of the elderly, consider the use of video image analysis and feature recognition to aid the house-bound or institutionalized elder. If two inexpensive video cameras were placed in an individual's room, the occupant could be easily identified against the otherwise constant background. The outline of the occupant's limbs could then be input to a computer neural network, which would extract meaningful gestures that could be used as switching commands to control lights, heat, telephone, door access, nurse call or entertainment. The occupant could be mobile or confined to bed, or unable to speak or (conceivably) to exercise intentional control of his/her gestures. Gestures of persons in the room other than the occupant would be ignored. In addition to enhancing the occupant's independence, this system would benefit caregivers by monitoring the client's motion status. This would be accomplished without invasion of privacy, since no human would have access to the video images.

Potential Implementation of High Technology

In the normal course of development, high technologies will be incorporated into rehabilitation practice only after designers of rehabilitation equipment become thoroughly familiar with them. It is suggested that the process could be accelerated by establishing demonstration or test-bed projects in which (possibly several) untried cutting-edge technologies are experimentally applied to selected target needs, accepting the risk that application may be premature, but also accepting the potential for more rapid than expected maturation under the impetus of demand to solve real problems, and for serendipitous discovery of larger needs beyond the initial target.

A similar approach is that taken by the National RERC on Technology Evaluation and Transfer, which has recently been established at SUNY-Buffalo. Through the work of three collaborating organizations, this new center conducts technical, consumer and business evaluations of prototypes submitted by entrepreneurs, industry, research centers and consumers.

Acknowledgements

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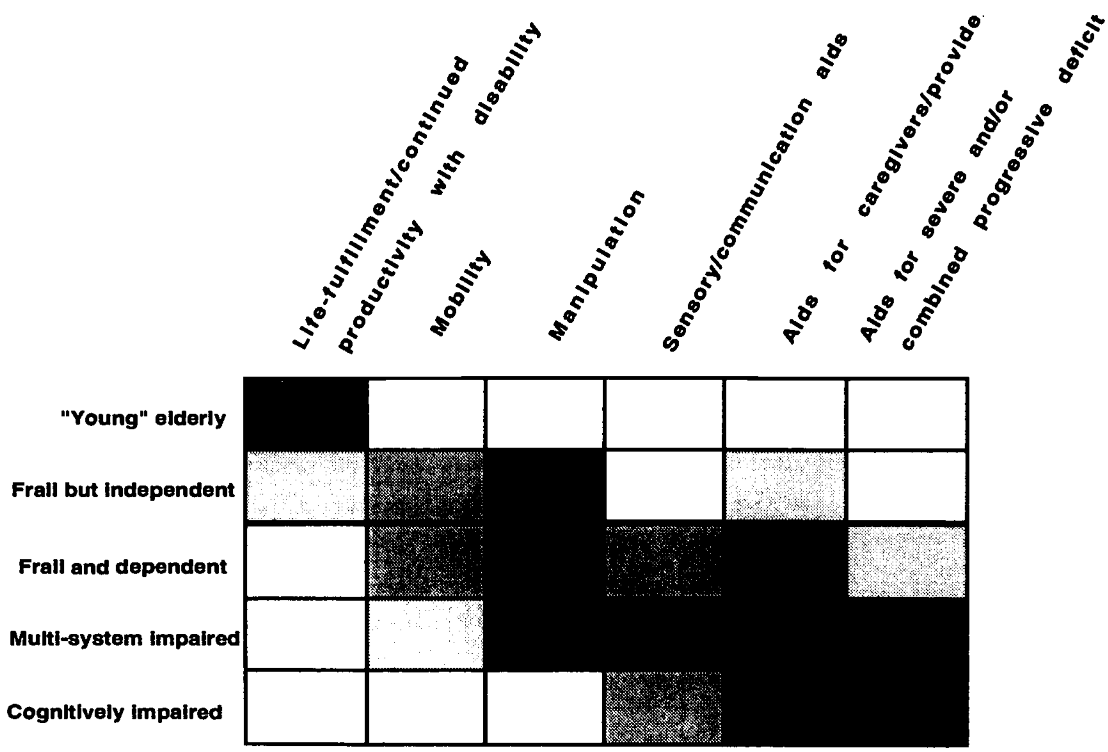

Matrix illustrating most promising (darkest shading) applications of high-technology R&D

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SIG-17
International Appropriate Technology

A LOW COST VACUUM CONSOLIDATION SYSTEM TO FACILITATE SEATING EVALUATIONS

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ABSTRACT

This paper describes a low cost vacuum consolidation seating evaluation system. The system consists of two major low cost components: a non elastic, flat vacuum consolidation bag and a controllable vacuum source. The vacuum consolidation bag can be readily constructed in variable sizes according to local requirements. Various vacuum sources are described; the most favoured is the workshop vacuum cleaner with electronic speed control.

BACKGROUND

Vacuum consolidation is a well known technique which has been used for some years to provide a variable support surface as part of the process for providing solutions for individuals with seating problems (1, 2, 3).

Seating Simulators are adjustable devices with multiple, typically planar, surfaces, which provide gross support to some type of compliant support interfacing with the seated individual (4, 5, 6, 7). Efforts have been made to design a low cost version of a seating simulator for use in developing countries, (8).

The technique of seating evaluation using vacuum consolidation typically uses round beads as the support medium and platilon bags or latex bags to contain them. The bead filled bags are placed on a seating simulator and the individual is seated in the simulator. The beads are then manipulated to provide the needed support and consolidated by a vacuum to maintain the desired shape.

In the hands of knowledgeable individuals, the combination of vacuum consolidation and an adjustable seating simulator is a very powerful tool in helping to resolve difficult seating problems. Further combination with a pressure measurement technique provides an even more versatile tool. A low cost pressure measurement system has been developed and is currently being made and distributed in small numbers as part of an educational program in Ajoya, Mexico, (9).

The materials used currently are relatively expensive and therefore make this a difficult technology and knowledge base to transfer.

OBJECTIVE

The emphasis of this project is to increase the availability of seating and positioning evaluation technology by developing a low cost, simple vacuum consolidation system which can be reproduced easily using available materials. Local resources can then be applied to produce locally appropriate solutions.

APPROACH

Current techniques which produce good conforming contours use either latex or platilon bags, which are stretched, under vacuum, to achieve the desired shape. The technique described here uses a low cost, flexible, non elastic bag filled to about 1" (25mm) with the support medium. Under light vacuum this can be made to conform to a variety of shapes with ease and then consolidated in the normal way.

To provide bead consolidated seating one needs a vacuum source which can be a vacuum cleaner, pump or adapted bicycle pump, hoses, valves, bags, and a support medium inside the bags to form the desired shapes.

METHOD

First the garbage bags are filled with the support medium. The since garbage bags are not as elastic as traditional materials the cannot be over filled. With the bags laying flat a 1" layer of beads works nicely and at the same time saving on the total amount of support material being used.
Although the "heavy duty" (1.1 mils) bags perform best the least expensive bags performed adequately.

Styrene beads are used to fill the bags. Also, we have experimented with chopped styrene packaging materials and chopped popcorn for the support medium and these materials may be promising with further investigation. The bag is then sealed. The better the seal the more successful the process. Start by laying the bag down flat with the open end facing toward yourself. Then cut a 3 inch slice along each side of the bag creating two flaps. Clean

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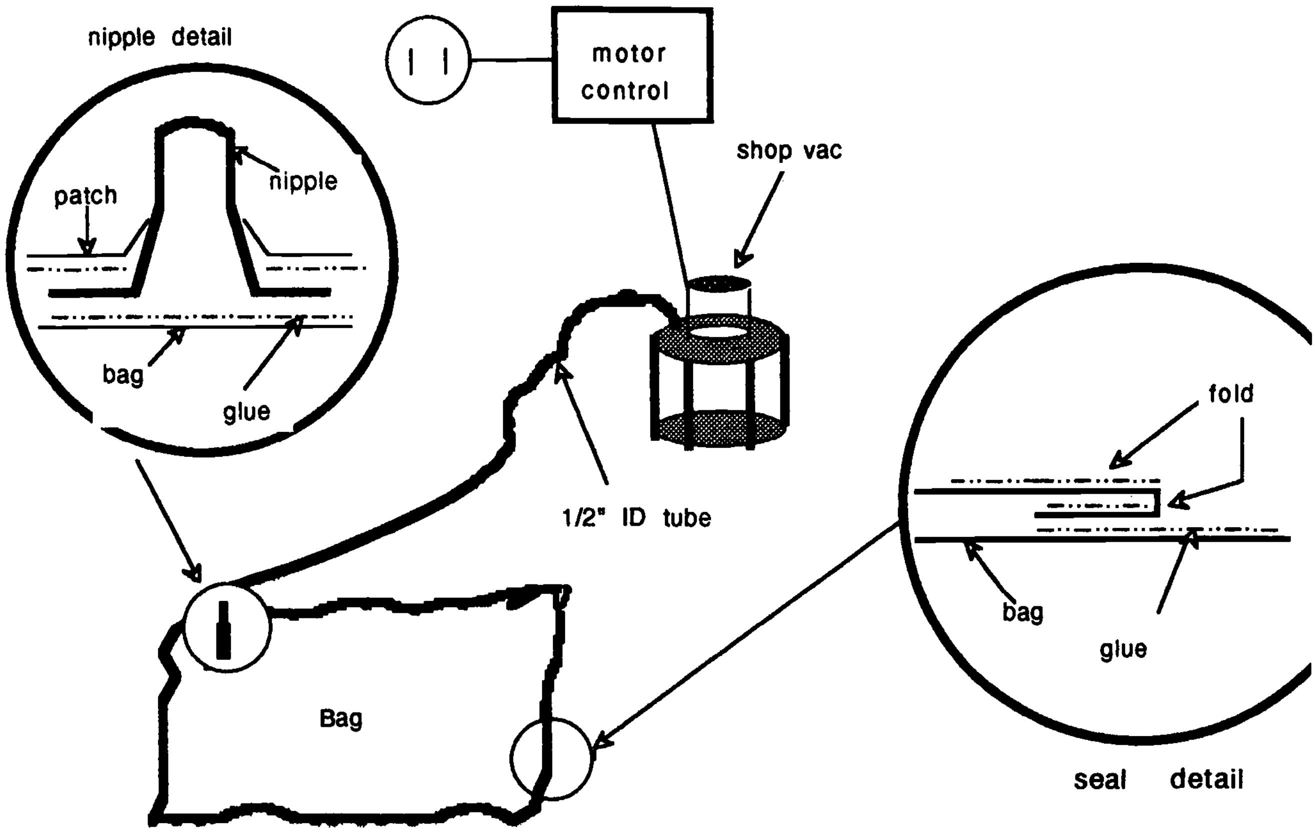

all the areas to be glued with acetone to insure good adhesion of he contact cement. The outside of the top flap is coated with contact cement, allowed to become tacky, tucked under and glued to the inside of the bag below the bottom flap.

Next a 2 inch wide area of glue is applied to the inside of the bottom flap and to an area 1 1/2 inches wide on the outside of bag along the fold that was created by the top flap making one continuous 3 1/2 inch wide area of glue. After the glue becomes tacky the bottom flap is folded over with 1/2 of the bottom glued area being folded with it. Then the contact cement is allowed to dry thoroughly .

Duct tape has also been used successfully by folding the top flap under and inside the bag and then applying the tape along the fold and beyond the edge of the bag and folding the tape over the edge of the bag. Then the bottom flap is folded over the top of the bag and taped again with the tape folding over the outside edge.

Next a baby bottle nipple is glued to the bag to provide a connection for the hoses. First a 1/4 inch by 1/4 inch cross is cut into the bag at the desired location and a small piece of foam is placed in the nipple to act as a screen preventing the medium from flowing up the vacuum hose. The area around the incision and the bottom of the nipple is coated with contact cement. After the contact cement becomes tacky the nipple is pressed firmly in place.

A 3 to 4 inch circle is then cut from another scrap bag and a 1 inch x 1 inch cross is cut in the center of the circular patch. Contact cement is then applied to the patch and to the area around the baby bottle nipple and on the nipple up to the area of the nipple that would protrude above the bottle. The patch is then placed over the nipple through the incision and applied to the bag thus creating a good seal.

A piece of 1/2 inch I.D. PVC tubing fits nicely over the nipple and makes a good seal. When a constant vacuum is applied by a, vacuum pump or sweeper, the mold becomes ridged and the nipple collapses slightly introducing a small leak into the system and becomes a self regulating device that prevents to much vacuum .

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VACUUM CONSOLIDATION

We have found that the garbage bags work satisfactorily in seating evaluations. When a bag isaccidentally punctured a repair is easily made with duct tape. Each bag takes about 15 minutes to make.

A small shop vac type vacuum cleaner equipped with a motor control can be used as the vacuum source.
The motor control controls the speed of the motor and regulates the amount of vacuum. Vacuum can also be controlled by introducing a small leak into the system.

An adapter used to fit small tubing to the vacuum can be made by cutting a plug from a 1 inch to 2 inch thick piece of wood sized to fit the vacuum hose opening. Then drill the appropriate size hole for the tubing trough the plug.

MATERIALS

typical shop vacuum --------	$50.00
PVC tubing 30 ft.---------------	$ 9.00
styrene beads------------------	$ low
1.1 mil garbage bags / 10--------	$ 2.85
baby bottle nipple / 3------------	$ 0.85
contact cement / qt.--------------	$ 5.00
speed control ------------------	$50.00

RESULTS

The vacuum consolidation system has been successfully used in seating evaluation in combination with a seating simulator.

ACKNOWLEDGEMENTS

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MANAGED COMPETITION IN WHEELCHAIR PRODUCTION: A TRANSITION FROM PLANNED TO MARKET ECONOMY

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ABSTRACT

Wheelchair building projects in Russia must confront a series of conditions unique to former Communist countries. As part of the Soviet Union, Russia had a centralized, planned economy. That economy is breaking down, but there is not yet a free market infrastructure to take its place. This means that special production and marketing problems must be solved in addition to the usual technological problems. Russia also has a developed architectural infrastructure which is extremely inaccessible to wheelchair riders. This limits the usefulness of wheelchairs and acts as a brake on wheelchair production. Projects to develop wheelchair production must promote competition and be coordinated with a comprehensive social and political program to remove environmental barriers to wheelchair travel.

Introduction

The Wheeled Mobility Center at San Francisco State University is implementing in wheelchair production an innovative model for economic development in the New Independent States. We are setting up a group of three small, independent, competing, privately-owned wheelchair factories, aided by a marketing and technology support system. Our goal is to keep prices low and quality high. We want to encourage technological innovation and improve the odds that these fledgling industries will survive to maturity.

The state monopoly over wheelchair production in the former Soviet Union is crumbling. While the monopoly existed, only a few different types of wheelchairs were produced which poorly served the needs of disabled consumers. Now, the removal of legal barriers to private ownership in Russia presents an unprecedented opportunity to develop a vibrant competitive wheelchair industry. The success or failure of development efforts will be partly determined by the economic models they are based on.

One model of assistance would replace the state monopoly with what is effectively a private monopoly. Huge excess industrial capacity, idled by the end of the cold war, presents international development organizations with the tantalizing possibility of setting up very large wheelchair factories to take advantage of economies of scale. Although the first wheelchairs built would undoubtedly incorporate some design features not presently available in Russia, continuation of monopoly would stifle further innovation and inevitably lead to a rise in prices and a decline in quality. This model for developing wheelchair production in Russia fails to take into account the vital importance of competition as the engine of economic and technological development.

A second model would merely create a general environment conducive to private enterprise by removing legal barriers and economic disincentives to profit-making activities. Although this model permits competition, it fails to consider two critical facts. First, the playing field is not level. Large, private wheelchair manufacturers with plentiful capital will make it difficult for small manufacturers to survive, thereby destroying the rich competitive mix which characterizes the wheelchair industry in most industrialized countries. Second, since most small businesses even in the United States fail, a system of support mechanisms is needed.

We have chosen to set up three factories because that is the minimum number to ensure competition should one enterprise fail. Each one of the three factories in the Wheeled Mobility Center's model of managed competition is expected to produce between 50 and 300 wheelchairs per month at full capacity. By tapping resources outside our 2-year AID grant, we plan to expand the network throughout Russia and other countries of the Former soviet Union as time and money permit.

A Marketing Support System

The greatest problem facing the one factory now in production is marketing. Soviet manufacturers never had to market their products because nothing was built that had not already been sold by or to the state. The Soviet wheelchair monopoly also never spawned retail stores and repair shops.

The Russians' lack of marketing experience is compounded by disabled people and their families' lack of incentive to purchase a wheelchair. Because wheelchairs were given away, disabled people have never developed a sense of themselves as consumers. Typically, disabled Russians who are fortunate enough to have a wheelchair have received a one-size-fits-all model from the government. The result is a chair that rarely fits, is uncomfortable, cannot squeeze through doorways, is too heavy, and generally will not support an active lifestyle. Moreover, having received a free wheelchair, the recipient is not motivated to keep the chair in good repair. Instead, he delays maintenance expecting to get the next chair for free. This is especially true for a family living on a subsistence income, where hard choices about expenses must be made everyday.

Recognizing this, our development model incorporates a complex marketing support scheme centered around the Novosibirsk Regional Disabled Sports Club "FINIST", a group of local disabled activists. Self-help organizations of disabled people, especially wheelchair riders, are ideal support groups for wheelchair factories. These groups are highly motivated because their members will be the immediate beneficiaries of low cost, high quality, readily available wheelchairs.

Competition will be promoted and managed by FINIST through a series of social and economic programs. To create a guaranteed market, FINIST will administer a revolving consumer credit fund. The fund will issue vouchers to qualified loan applicants. The applicants will then be free to exchange their vouchers for the wheelchair of their choice at any of the three factories. This mechanism will empower the disabled consumer by giving her a choice of wheelchairs, while at the same time letting the factories know what features they need to build into their chairs.

FINIST will also be the majority shareholder in a specialty parts and equipment joint venture with the wheelchair manufacturers. This joint venture will supply each of the shops with hard-to-come-by parts and will allow for shared use of expensive equipment. With FINIST as the majority owner, no factory will be able to monopolize scarce parts or have sole access to expensive equipment.

The three factories will be directly supported by a FINIST-run mobile wheelchair repair service. In addition to regular repairs, this service will perform warranty work and in the process compile a record of design and production problems. The mobile repair service will also help make inexpensive adaptations to disabled people's apartments to make them more accessible and easier to live in. FINIST will also run a design and testing center where wheelchair riders can actively develop new designs and provide feedback to the factories to ensure that the wheelchairs produced have the features that riders desire.

The Problems of Wheelchair Access

Russia's ubiquitous barriers to wheelchair travel have induced an attitude of resignation and dependence in disabled Russians and their families. They choose not to spend scarce resources on a piece of equipment that may do little more than get a person from his bed to the kitchen table. A person will be motivated to buy a wheelchair if he can go places with it. To provide this motivation, FINIST has undertaken the task of creating a wheelchair accessible infrastructure in Novosibirsk. With technical assistance from the Wheeled Mobility Center, FINIST is beginning a series of model demonstration projects to remove architectural barriers and provide wheelchair accessible transportation.

The architectural barrier removal program begins with a project to make the municipal sports stadium and the area around it more accessible. When completed, the area will have curb ramps and at least one wheelchair accessible bathroom. The accessible transportation program will begin with the acquisition of a few vans to serve as the nucleus of a paratransit system.

These manageable, practical projects will: 1) improve the access of wheelchair users so they may take advantage of FINIST's (and other) programs and services; 2) provide disabled people with an incentive to buy a wheelchair because there will be activities in which they will now be able to participate; and 3) serve to demonstrate to wheelchair riders and the municipal government what is needed to make an environment wheelchair accessible and how wheelchair riders will benefit.

As soon as we can raise additional funds, FINIST plans to establish a Legal Advocacy Center. This Center will develop a model municipal accessibility code for Novosibirsk which would include making all new construction wheelchair accessible. This kind of systematic approach is the only way to ensure significant and widespread improvements in wheelchair access.

One of the keys to success in this project is to develop effective organizations run by people with disabilities, because only disabled people themselves have the interest and commitment to address and solve the problems which uniquely affect them. A second key is to follow a model of development which promotes vigorous economic competition while at the same time protecting and nurturing each new-born enterprise. This provides the best hope for Russia's wheelchair industry to move away from monopoly and to continually evolve better designed, better built and lower cost wheelchairs.

Acknowledgments

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LOW COST PRESSURE MEASUREMENT TECHNIQUE FOR INDIVIDUALS WITH SPINAL CORD INJURY

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ABSTRACT

This paper describes the features of, and experiences with, a low cost pressure measurement system for use in the evaluation of seat cushions used by individuals with spinal cord injury. The system consists of approximately ten feet of 1/8" inside diameter clear flexible tube connected to a balloon. This system is filled with coloured water and mounted on a cloth backing which indicates pressure levels using colour codes of green, yellow and red..

BACKGROUND

Pressure measurement techniques have been used for several years to help with the prescription of wheelchair cushions and to educate wheelchair users in pressure sore prevention. Early studies, (1), provided guidelines of acceptable pressure/time intervals for the buttock/cushion interface which are still used today. Pressure measurement devices have evolved from single cell air bladder transducers that take single measurements, to multiple sensor units which provide continuous samples and display dynamic pressure maps. These devices work on various principles, pneumatic, hydraulic, and piezoelectric and have been analyzed in some depth for accuracy (2, 3, 4). Prices for these devices vary from about $200 for single cell sensors to $15,000 for the multiple sensor type with computer output (5, 6, 7, 8). Clinically these devices can be very useful in giving comparative information for the selection and/or customization and optimization of seating support surfaces (9, 10, 11).

PROBLEM

In developing countries spinal cord injuries are normally (80%) followed by death within 2 years as a result of pressure sore related problems, (12). To address this problem, this project has focused on the development of a low cost pressure measurement device to help in the fitting of seating support surfaces in order to reduce the incidence of pressure problems in this population..

OBJECTIVE

The emphasis of this project is to increase the availability of seating and positioning evaluation technology by developing a low cost, pressure measurement device and training package which can be reproduced easily using available materials. Local resources can then be applied to produce locally appropriate solutions.

METHOD

Low cost devices which aid in the rehabilitation process, such as wheelchairs locally manufactured for about $150 are being introduced in some countries (13).
For many years pressure has been measured using columns of liquid, typically water or mercury, and clinical measurements of blood pressure and "seating pressure" are expressed in mmHg (millimeters of mercury).

The following specifications were developed:

1. Cost and the availability of materials are the major factor in making devices available in the "real world". The target manufacturing cost was set at $25.00.
2. There is much argument about what are appropriate pressures and a large amount of research has been carried out and continues to be carried out in this area. As a pragmatic attempt to develop a clinically useful system the following pressures were decided upon:
   - indication of pressure equivalent to 0-50, 50-75, 75-100mmHg (safe, caution, unsafe).
3. Performance. The system should be simple to manufacture and operate, functional, reliable, and easy to maintain.
4. Education. Appropriate educational material should be developed.

This was followed by brain storming, prototyping and the design as depicted in the figure. A coloured water column is used in a clear flexible 1/8" internal diameter tube about ten feet long. To this is attached a balloon whose flat dimensions should be approximately:

3-3.5" long overall
2.5-3" to the start of the neck
1.25" widest width

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PRESSURE MEASUREMENT SYSTEM

This assembly is attached to a cloth backing with a top tie (string) for hanging up and a bottom tie for hanging a weight (stone) to straighten things out. 36" of free length is allowed at the lower end.

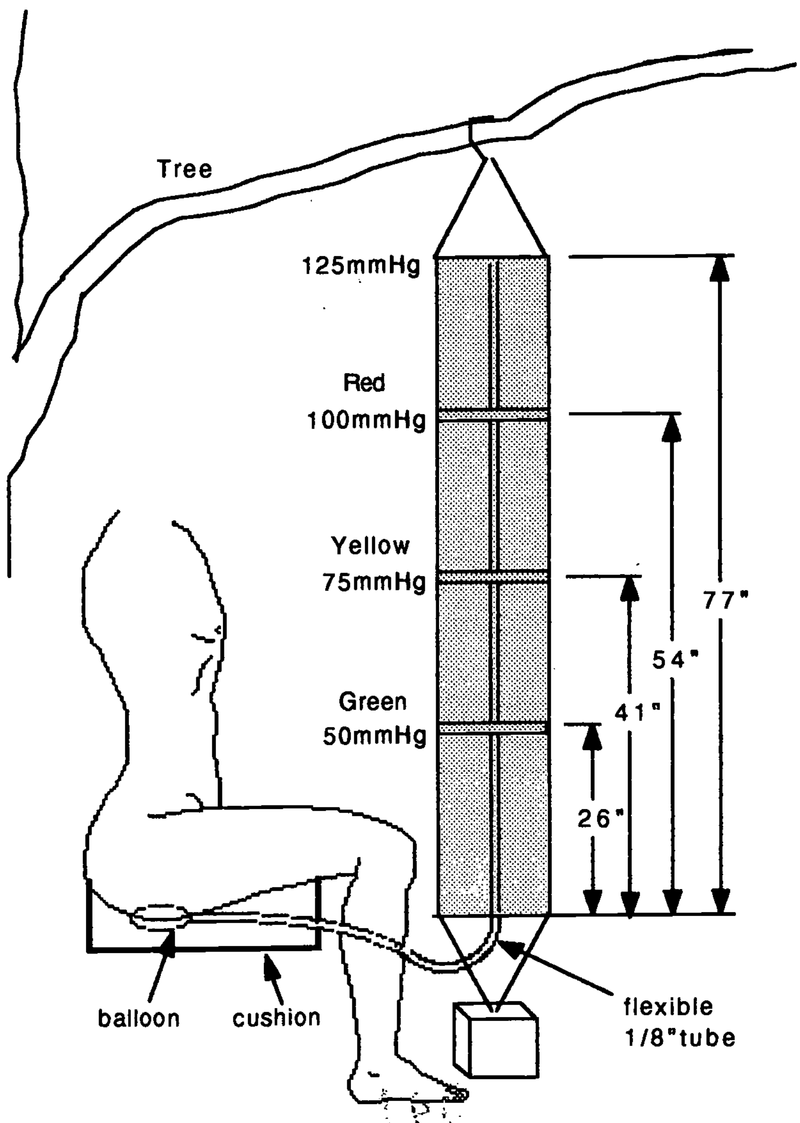
RESULTS

The Pressure Measurement System costs about $2.00 for a single unit. Experience has shown that a single unit is more manageable than multiple units.

More than 50 people have been trained in three different workshops in Mexico, in the use and manufacture of the Pressure Measurement System.. This was done in the context of hands on workshops in which pressure relief cushions were manufactured for wheelchair riders using available sustainable technology in which the design of the contour was achieved by iterative pressure measurement. The wheelchair riders themselves are always trained in the manufacture of the Pressure Measurement System and their personal use of it for evaluation changes and the quality of the cushion support over time. Simply put, they are trained to check their pressures on a regular basis.

Initial response has been favorable.

The Pressure Measurement System clearly involves appropriate sustainable technology.



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ADVANCEMENT OF APPROPRIATE REHABILITATION TECHNOLOGY IN INDONESIA

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ABSTRACT

In Central Java, Indonesia, a child spent eleven years lying on the earthen floor of his home in a rural village community. Another child, at a non-government organization (NGO) rehabilitation facility was supplied with a wheelchair when his weakening condition and the lack of accessible dwellings would not permit his independence. These two cases were studied while developing seating devices for them, to examine cultural, social and economic factors influencing appropriate technology, device assessment, design and fabrication.

By sharing knowledge and ideas across the gulf of cultural differences, not only can experiences of rehabilitation technology development be shared throughout the developing world, but basic human needs and values remind us how to focus both low and high technology solutions.

BACKGROUND

Of Indonesia's 187.7 million people, 72% live in rural areas. Java alone holds over 96 million [3]. In 1986 the Department of Social Affairs estimated 3.11% have a disability, other sources have made higher estimates, suggesting more than 5.8 million people have disabilities[1].

Hospitals and rehabilitation institutions in Indonesia serve 10% of the estimated disabled population. The government funds 33 rehabilitation institutes in 21 of Indonesia's 27 provinces with NGOs supporting 352 other centres[1]. A recent pilot survey (derived from WHO) indicates 70% of people with disabilities in villages are not helped at all by aides or other people. For 48% of those who are helped, receive this help from their mothers[4].

Community Based Rehabilitation (CBR) can be described as an approach to grass-roots rehabilitation, or as 'any activity which results from decisions made by the community and their disabled persons in particular, and which aims to enable disabled persons to gain more for themselves or their children of what they need.'[2]. CBR also aims to increase basic rehabilitation services for, by and in the community. In this way, some basic intervention reaches more people, simple case needs can be met in the community, and more complex cases can be identified and referred to suitable institutions.

Examples of community focused programs in Indonesia are:
(1) group homes in village communities,
(2) under five disability detection.
(3) outreach identification/referral to institutions.

Within these and other existing programs there is a great need to identify characteristics, improve and expand on appropriate rehabilitation technology.

Several institutions and hospitals, both government and NGOs, in central Java, supply similar standards and types of assistive devices, primarily including;
(1)Prosthetics: lower limb - aluminum exoskeletal with wood or rubber foot, AK and BK, upper limb - cosmetic, wood,
(2) Orthotics: iron leg calipers, orthotic shoes,
(3) Other: crutches, walkers, wheelchairs.

No plastics nor seating devices were utilized.

Training for the majority of technicians in these facilities is 'in-shop'. Some have been trained in India or at other institutions. One of the weaknesses observed at several facilities and identified by technicians at one, is the lack of coordination between the doctor, technician and therapists to ensure greater effectiveness of devices and functional capability of the client.

OBJECTIVE

To identify core characteristics of rehabilitation technology (device assessment, design, fabrication), influenced by the culture, society and economic conditions in Java, Indonesia, specifically affecting technology appropriate at the community level.

APPROACH

Background study of both institutional facilities and CBR programs and concepts provided a base for two case studies in which assistive devices were developed and made together with family and community members.

Both cases involved children with potential to be helped by appropriate seating, an area of rehabilitation technology which appeared to be least practiced or generally understood. Although trained therapists demonstrated an understanding of seating concepts, the available technicians had no background in this area.

One case targeted a very poor family in a rural community where neither government health services nor a pilot CBR program had been able to assist the child. The other case targeted a non-government disabled children's organization where both therapists and P&O technicians were involved.

RESULTS

The first case, an eleven year old boy, Edi, had hydrocephalus resulting in an extremely enlarged skull, some retardation and visual impairment. We designed and built a seat with an adjustable slanted back and head support, visible in *figure 1*, and a table for work space, as reflected in *figure 2*.

Figure 1. Checking fit of chair supports to Edi.

Figure 2. Chair and table after two weeks of use.

The hierarchical structure of government and society, affected the device design process when a local high level government administrative official suggested that as Edi got better, there would be a need to have him sit upright. Thus the adjustable chair back was made to reach 90 degrees, although contraindicated with the present simple head support design. His parents agreed not to use the upright position and exercised great caution with Edi. We later emphasized improvements Edi could make e.g. learning to eat and drink independently.

Indonesian social values stress community and the nation, above the individual, as is apparent in their national philosophy, the Pancasila. Family and many community members worked together, as they are accustomed, to fabricate the chair. Thus, to encourage community input the initial design was left flexible providing Edi's needs were met.

Another aim of the project was to work within the economic limits of the case. Interestingly, when we suggested the use of bamboo, a readily available, cheap and strong material, the village officials and the community worker said it was not strong enough. We later deduced that this community feels a bamboo chair represents poverty. It was thus unacceptable, despite the fact the family was poor.

The second case, a twenty-two year old boy, Subriadi, had muscular dystrophy resulting in a severely curved spine, very weak arms and inability to ambulate. We developed a seat which would fit inside his wheelchair, shown in *figure 3a*, with a loose strap across the chest, supports on both sides and a cushion fitting the shape of his back, being worked on in *figure 3b*.

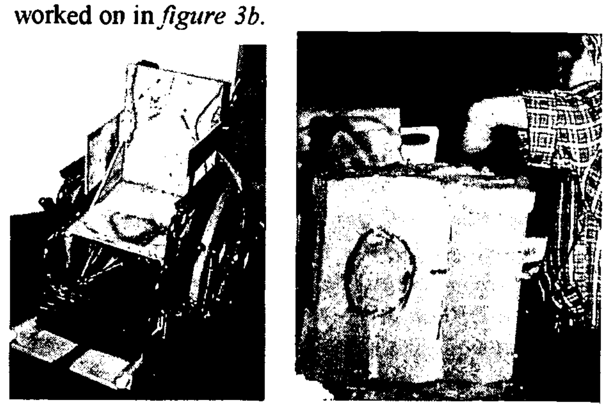

Figure 3. a. Wooden seat frame inside wheelchair. *b.* Layered foam back support, carved to fit posture.

Government education currently teaches a textbook approach to problem solving, where problems are categorized to fit predetermined 'textbook' solutions. As a result, straight-forward physical and functional problems (e.g. inability ambulate,

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missing limb, or limb deformity) are the primary focus of assistive device prescription at many institutions. Physical assessment of Subriadi focused primarily on his inability to ambulate. Treatment did not address potential further complications, e.g. breathing or digestion, resulting from the severe deterioration of his posture. However, the lack of funds for higher training and more equipment is also a factor.

An understanding of social and cultural norms facilitated a foreigner and technicians working together. However, neither the design nor fabrication were largely influenced by these.

DISCUSSION

The term 'appropriate' in reference to rehabilitation technology can encompass cultural, social and economic factors of technology intervention, implementation or fabrication in any context.

Characteristics of rehabilitation technology which currently provide guidelines for many international community level applications include;

(1) device suitability to a child's needs within their own culture and community environment,
(2) suitability of materials amongst those available and commonly used in the region,
(3) affordability,
(4) basic community education, field worker (or community worker) training and resources.

Additionally, these case examples occurring during three months in the field, helped to highlight criteria specific to Indonesia. Such as:

(5) simplicity and flexibility of design, i.e. the basic functional concepts for designs should be simply presented allowing community involvement without detracting from required device performance/use,
(6) clear linkages between physical limitations of client, device design/type and potential for device use, so that categorization of a broader range of problems including more complex problems is possible,

and specific to institutions;

(7) training to increase fulfillment of technology needs, specifically seating,
(8) improving coordination and feedback between the rehabilitation team, so that devices are evaluated during use and can be later adjusted by technicians, and potentially improved to better suit needs of Indonesian children.

Perception of need is one of the major keys to identifying needs cross-culturally. Not only is it important to understand how people view disability in their communities but also how they view the role of technology intervention even on the most basic level. Even the poorest of peoples want a quality product in their own context, thus affecting material selection and design, as with bamboo for Edi's chair. A quality approach to design and craftsmanship will be a positive influence on perception of device function by the community, as is also the case in North America.

Prioritizing needs of people with disabilities also varies considerably in different cultures. Often immediate needs, such as Subriadi's inability to walk, outweigh long term needs, such as the probability that he would not be able to use the wheelchair for long due to deterioration of his muscles and posture. Edi's family on the other hand, benefited from the mother having more time for her own work, and also empowerment from feeling they had been able to better provide for their son. If the perception of needs can be shared across cultures, people can work together to expedite identification and advancement of appropriate rehabilitation technological characteristics such as those identified here.

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Easter Seal Student Design Competition

1994 Easter Seal Student Design Competition Project Entries

Development of a Multisensory Interface to Allow Blind User Access to Graphics* Rafael Arce-Nazario, University of Wisconsin-Madison, 809/855-2000

The Design and Manufacture of a Custom Wheelchair Madeline D Austin, Alfred University, 607/871-2100

Development of an Efficient Computer Interface for Persons with Mobility Impairments* Jeffrey B Bishop, University of Iowa, 319/335-6134

Seating Simulator - A Simple, Low-Cost Evaluation Chair David Caplan, Paul Hendrix, San Francisco State University, 415/668-9540

Design of an Automated Drink Dispenser for the Disabled Anastasia Cheetham, University of Toronto, 416/964-7737

Interactive Science Experiments Allowing the Inclusion of Students with Disabilities* Bridget Cooney, Darius Rydahl, Ted Marigomen, Gregory Wassick, David Sant, Obi Anusiem, Wayne State University, 313/577-3921

The Design of a Foot Actuated Control Interface* Greg Ensminger, Thomas Heil, California State University-Sacramento, 916/388-1557

A Weightlifting Machine for Paraplegics Todd D Gothard, Mississippi State University, 601/325-3282

Adaptive Golf Cart Seat for the Physically Challenged Cary Gumbert, Massachusetts Institute of Technology, 617/262-3192

The Flipper: An Augmentative Device for the Automatic Removal and Retrieval of a Wheelchair Mounted Tray Robert S Hirsch, Rensselaer Polytechnic Institute, 518/276-8135

Switch Activated Dispenser for Packing* Roman Los, Daniel Zarewych, Kim Gilbert, Wayne State University, 313/577-3900

Easily Adjustable Sport-Wheelchair Parking Brake Matthew P Manning, Cary Gumbert, Jeff Howell, John Feland, Massachusetts Institute of Technology, 617/225-6616

Student Design of a Fishing Reel Conversion for Use by Physically Challenged People Stacy L McDougall, Phillip B Riemer, Rod K Burchby, University of Saskatchewan, Canada, 306/955-4018

The Design of a Hydraulically Powered Elevating Toilet Seat** Mark Musolino, University of Pittsburgh, 412/361-7561

Caster Tri-Modal System: A "Roller-Ball" Caster Mechanism M Todd Nester, Mississippi State University, 601/325-4849

The Utilization of Universal Design Principles in the Development of an Ergonomically and Cognitively Simpler User Interface David J Sant, Apurva Mudappa, Wayne State University, 313/486-1140

A Secondary Joystick Adapter for Force Reduction Michele S Suszko, Enrico R Cafaro, Steven A Yany, Worcester Polytechnic Institute, 508/831-5498

The Walker Pack: An Innovative Carrier for Storage and Transport of Personal Items Angela R Thalls, University of Washington, 206/783-1876

A New Switch Actuator Design that Enhances Proprioceptive Feedback in the User of Limb Position** Daryl Thomas, Louisiana State University, 504/388-1495

The Design of a Portable Personal Transfer Aid Mark E Tippins, Queen's University, Canada, 905/623-2468

An Oscillating Chair to Measure the Dynamic Stability of the Human Torso Chamaine Toy, Robert O'Toole, Tse-Yong Yao, Stanford University, 415/776-6010

*Winning Projects; **Honorable Mention Projects

1994 Easter Seal Student Design Competition

We in the Rehabilitation Technology profession have witnessed literally thousands of new products and interventions over the past decade, but I am constantly aware of how many areas still need our wizardly attention. I dare say that nearly every rehabilitation clinician, given the opportunity to reflect on some of their recent cases, could easily identify some patient's problem, for which there exists no sources for readily available commercial technology. The fact remains that few of these clinicians, be they OTs, PTs, Augmentative Communication Specialists, etc., have access to the engineers who may be able to spare the time and resources needed to come up with viable solutions to these problems. That's exactly why this competition continues to flourish, by identifying the types of projects that we have come to expect. That also helps explain why our judging gets tougher year to year; because, these young engineers have learned exactly where to turn to identify "Real World" issues and problems. By having their finger directly on the pulse of the clinical community, we are seeing projects that are unique, yet universally understood, forcing the authors to investigate all possible commercial interventions or similarities before re-inventing the wheel. And by choosing our judges from among the clinical community and consumers, we are seeking to insure that our choices represent very real needs. In short, it is very easy to identify with these projects if you work in the rehabilitation professions.

In years past, the esoteric was mixed with the futuristic; needs were often mingled with "wants," simply to impress the author's technology prowess. As I promised last year, we are going to publish the entire list of 1994 entrees. The practicality of this year's projects, compels us to at least share the titles and authors with the intended beneficiaries. The entire purpose of this project and it's sponsor, is to inform the rehabilitation community of such works.

We truly regret that we could not print them all, however, the next best option would be to allow you to contact the authors personally, should you desire closer contact regarding their particular projects. I am sure they would be happy to send out a copy of their submission, or to discuss the details of their project. I will continue to press for future inclusive publications of ALL entries. For now however, please read and enjoy our choices for 1994. This is a very special year for our competition and it's sponsor. We commend and acknowledge the National Easter Seal Society for 75 great years of service to the United States. It is also important to note that 1994 marks the 10th anniversary of RESNA's cooperation with the National Easter Seal Society in sponsoring this Student Design Competition.

We can only hope that the next 10 years will be as fruitful, but if the past several years are any indication, I can hardly wait to see what will transpire. Please take the opportunity to meet and congratulate our 1994 winners, as we converge on Music City!

David F. Law, Jr.
Chair, Easter Seal Student Design Competition

Development Of An Efficient Computer Interface For Persons With Mobility Impairments

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ABSTRACT

Visual Keyboard allows individuals with mobility impairments who cannot type with a standard computer keyboard to enter text using a pointing device or ability switch. A graphical representation of a keyboard is displayed on the computer screen. Visual Keyboard automatically launches and resizes a previously selected Windows application when Visual Keyboard is launched. Keys selected by the user are sent by DDE to the Windows application. A new keyboard layout has been developed which reduces the distance the cursor must travel in order to enter text when a direct selection entry mode is used. The software is in use at several test sites for applications such as word processing, spread sheets, and Internet access.

BACKGROUND

Computers are now common in the workplace, schools, and homes. Since computers can be adapted for use by disabled individuals, the opportunity exists for individuals with mobility impairments to live and work in a way that was not possible before computers were readily available.

Many individuals are unable to type with a standard computer keyboard because of mobility limitations such as those caused by cerebral palsy (CP), multiple sclerosis (MS), amyotrophic lateral sclerosis (ALS- Lou Gerhigs disease), severe arthritis, paralysis, stroke, amputation, and other causes. Several types of input devices are available to use whatever movement that a person can control consistently as input to control a computer [1] [2].

STATEMENT OF PROBLEM

A means is needed to allow people who cannot type using a standard computer keyboard to use alternate input devices to interface with a computer effectively. The interface should allow users to input text and should support a variety of input devices to accommodate individual needs.

RATIONAL

The interface was designed to work with existing computer hardware and input devices. Visual Keyboard (VK) runs on IBM compatible computers under Microsoft Windows. VK supports input from a pointing device (such as a mouse, trackball, headmouse, or EyeMouse [3]) or an ability switch.

Commercial hardware and software have been developed to allow users with mobility impairments to enter text by various means. Many of these systems are designed as 'stand alone' packages which allow users to work with specialized software provided with the product. Visual Keyboard was designed to work with existing software so that users with mobility impairment can use standard Windows applications such as Microsoft Word for Windows. Visual Keyboard also provides features which include automatically launching and resizing the desired Windows application, launching a user defined macro on startup, and recording a data log containing the user's typing rate and other performance parameters to help determine the most effective settings for each user. Visual Keyboard also incorporates a direct selection entry mode using a point device and a scanning entry mode using an ability switch in the same software package.

DESIGN

Visual Keyboard displays a graphical representation of the keyboard on the computer screen and allows the user to type by selecting keys using a mouse, trackball, EyeMouse, ability switch, or other input device. Text may be entered using any of the following modes: point-and-click, dwell-time, or scanning mode. In point-and-click mode the user positions the cursor over a desired key and clicks a button to generate a keystroke. In dwell-time mode, moving the cursor over the target key highlights that key and automatically generates a "click" after a period of time passes. No manual click is required. Scanning mode allows the user to select among groups of keys, then individual keys, using a button or switch. Keystrokes generated in each of these modes are sent to a background application via dynamic data exchange (DDE).

VK has many features which increase the effectiveness of the interface. When VK is launched, it automatically launches a preselected

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Windows application and resizes its window to the upper half of the screen. This reduces the amount of effort required to use the system. A user-defined macro can also be launched by VK at startup. This is useful for entering an Internet address and login identification if communications software is used. The autocapitalization mode, developed to expedite the entry of names and addresses for mailing labels, reduces the number of keystrokes required for this task by about 30%. A one-key-sticky-shift key is also included to make capitalization more efficient for general text entry. Glossaries in Microsoft Word for Windows can greatly reduce the number of keystrokes required by allowing the user to save commonly used text in a glossary, which is then invoked by typing an abbreviation followed by the Glossary key in VK. For example, "vty" could stand for "Very truly yours" followed by signature space and then the user's name.

Both auditory and visual feedback are provided for the user when a key is entered. Experience shows that this helps users feel more comfortable with the interface. Help screens are also available when working with advanced features of the program, such as selecting a startup macro and selecting the entry mode.

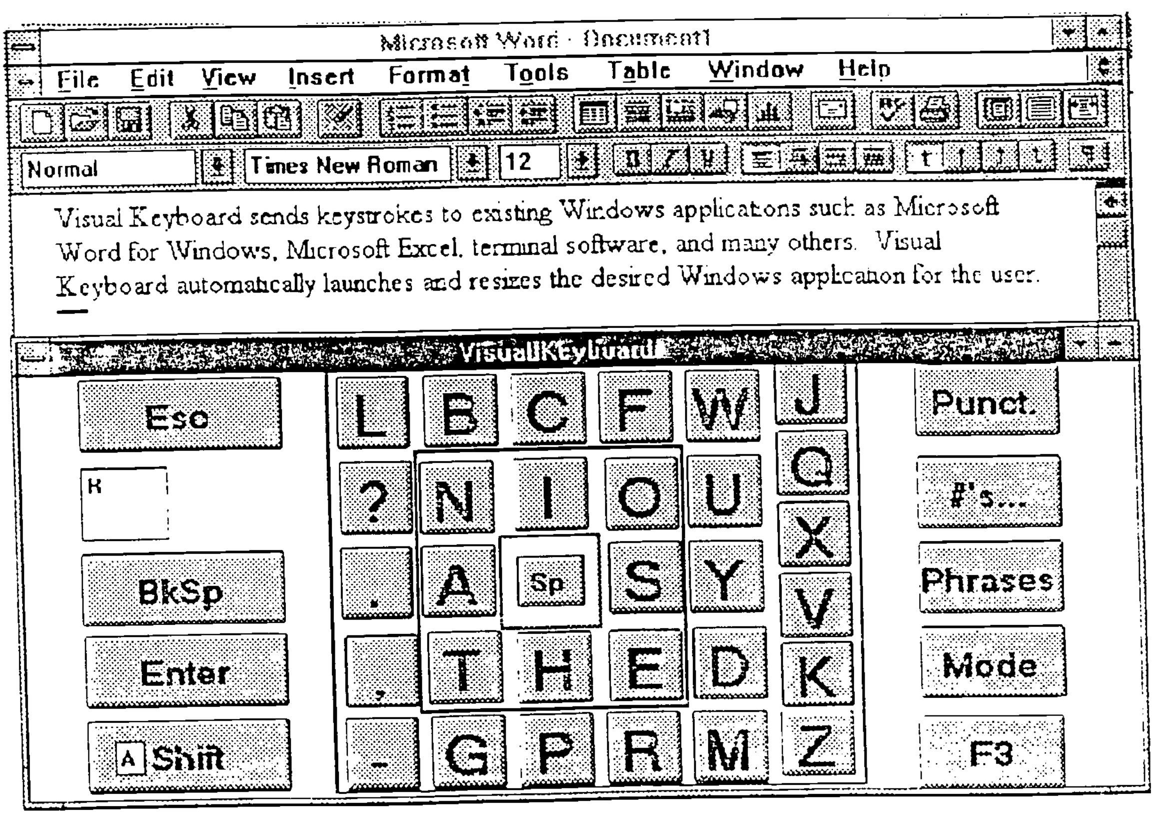
A new keyboard layout called Modified Dvorak layout was developed using information about the probability of transition from one letter to the next in addition to information about the frequency of occurrence of letters in text. This keyboard layout reduces the distance the cursor must travel in order to enter text [4]. Other keyboard layouts, such as an alphabetical layout and a QWERTY standard keyboard layout, are also available in VK.

DEVELOPMENT

Microsoft Visual Basic was selected as the programming language for the development of VK. Visual Basic provides access to DDE in Windows and powerful tools for object-oriented interface development. Another advantage of using Visual Basic is that its code is easy to modify. This has proven useful by allowing rapid addition of new features to Visual Keyboard to accommodate the needs of users at several test sites. VK was placed at test sites early in the development cycle to allow input from end users to shape its development. VK was developed with the Professional Edition of Microsoft Visual Basic version 3.0.

EVALUATION

In order to determine the effectiveness of keyboard



layouts for direct selection with a pointing device, a distance metric was developed. A text file is read by the computer, and the distance that the cursor would need to travel in order to type each letter with various keyboard layouts is determined using a table of key position coordinates. The Modified Dvorak layout that was developed is approximately 100% more efficient than the alphabetical layout and approximately 8% more efficient than commercially available frequency-of-use layouts in terms of the distance that the cursor must travel to enter text.

Learning curves were established to determine the amount of time required to learn the Modified Dvorak layout and other keyboard layouts such as the QWERTY layout and the alphabetical layout. Subjects entered text from a typing manual and the typing rate in words per minute was measured as subjects gained experience with the keyboard layouts. Preliminary results show that the Modified Dvorak layout may become more effective than others after about 30 minutes of use for persons without mobility impairment.

In order to evaluate the performance of the various keyboard layouts and entry modes in actual use, a data logging feature is incorporated in VK. The number of keystrokes typed per minute, number of 'delete' keystrokes typed per minute, keyboard layout, entry mode, and other variables are automatically recorded in a file while VK is used. The file can then be studied to evaluate the effectiveness of various keyboard layouts and entry modes and to recommend settings for the user. The data logging feature of VK will soon be incorporated at 14 test sites on 3 continents.

DISCUSSION

Visual Keyboard can be used with most Windows applications. At one test site, the Information Arcade at the University of Iowa, Internet access is available using VK. Electronic mail, FTP, gopher, discussion lists, and many other resources of the Internet are now accessible for people who cannot use a computer keyboard. At another test site a 32 year old man with cerebral palsy has been employed for the first time, using VK for entry of names and addresses for mailing and file labels.

VK allows people with mobility impairments to fully utilize the hardware and software most commonly used by businesses, increases the efficiency of text entry by reducing the number of keystrokes required for certain tasks, and allows an increased rate of text entry by reducing the distances between frequently occurring pairs of letters. The variety of entry modes available allows VK to be used by individuals with a wide range of mobility impairments.

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Interactive Science Experiments Allowing the Inclusion of Students with Disabilities

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ABSTRACT

The Detroit school system is working to improve accessibility to educational opportunities for children from "under represented" groups, this includes children who are physically disabled. Computers and related technologies are being applied to reduce or remove barriers for students who are physically challenged. Perhaps the most common approach is to identify an assistive technology that allows an individual student to participate in classroom activities. These are often customized, one-on-one adaptations. An alternative approach, used in this project, is to design the process so that it naturally supports inclusive activities. This project designed and built a system to stimulate interest in scientific studies for students in the 4th through 8th grades in The Detroit Academy for Science, Mathematics, and Technology, which is housed at the Detroit Science Center. This system consists of an interactive set of experiments arranged in a menu driven format. Universal design principles were used to create a system that would naturally support inclusive activities, thereby satisfying the overall objective of stimulating interest in science for able-bodied students as well as students with physical disabilities.

BACKGROUND

The Community Foundation for Southeastern Michigan is currently funding a project for Innovations in Science. One goal of the grant is to stimulate interest in science and technology for children from under represented groups - racial minorities, females and individuals with disabilities. The Enabling Technologies Laboratory at Wayne State University has collaborated on this project with, The Detroit Academy for Science, Mathematics, and Technology (the Academy), and the Detroit Science Center (DSC). The Academy has a limited enrollment, drawing students from the entire city. Students from other elementary and middle schools rotate through the Academy for short (one/two week) periods. In addition, the DSC hosts student groups from all over the greater Detroit Metropolitan Area.
As part of that grant our team designed and developed an Interactive Science Experiments system. The system is to be used by students in the Academy and as a demonstration system in the DSC's Discovery Auditorium. Engineering student volunteers, mentors, work with small groups of students, providing explanations, instruction and supervision. They will also conduct the DSC Discovery Auditorium demonstrations.

Accessibility is a particularly difficult issue for science, i.e., the manipulation of materials, the use of complex instrumentation controlled by rotary dials, push buttons and other cognitively and ergonomically difficult operations. The Foundation for Accessible Technology conducted a study, Models for Integration: Science and Technology, (MIST), which implemented systems for inclusionary science activities [1]. Our approach is very similar to theirs in that we not only develop the technological support, but provide the human, mentors, support need for student motivation.

MIST tended to focus attention on strictly computer related operations such as word processing, data base management, data presentation, etc. Our work differs from the MIST project in that we provide the ability to more fully integrate students with physical disabilities into science activities by enabling them to setup and control complex instrumentation and hence the experiments. The need for simplification arises from the need to reduce the complexity of experimental control so that elementary and middle school children can conduct the experiments. Hence the need to simplify the cognitive and ergonomic demands of the experiments provided an opportunity to include process structures and supports that naturally enable a very broad spectrum of students to access the system. This philosophy is central to the activities of the Enabling Technologies Laboratory, i.e., identify ways in which one can design product and process supports into products and processes improving operational performances by all users and hence naturally increase the potential for access by individuals with physical or cognitive disabilities.[2,3]

OBJECTIVE

The objective was to Design and develop an Interactive Science Experiments system that would stimulate interest in science and technology for children in the 4th through 8th grades. The system must also be accessible to students with physical disabilities and support naturally inclusive activities. This requirement derives from the need to reach students from under represented groups.

METHOD

Our approach was to design a system that would be easy for all elementary and middle school students to use. The intent of the system is to motivate - hence it should be entertaining yet also encourage learning. The specific experiments were negotiated with teachers from the Academy and reflect science curriculum in the 4th through 6th grades, i.e., motion, sound, vibration, and wave phenomena.The system had to support different levels of scientific, technological and educational objectives; phenomenalogical for the youngest children while allowing more investigative activities for the older children. The Academy teachers provide the curriculum material while our group provided the technological capabilities for experiments, i.e., the system.

The only access points for all users are interactive menus / screens on a PC. The graphical user interface (GUI) had to be familiar to the students, it had to suggest its function. The form of the GUI was developed in cooperation with the teachers at the Academy. The software buttons, slides, displays, etc. are all things the Academy students are familiar with from other programs.

The system opens with a main screen displaying a unique icon for each experiment. Currently, the student has a choice of five experiments. Figure 1 shows the equipment layout. One, is a strobe light experiment. Using a scroll bar displayed on the computer screen, the student can increase or decrease the rate that the strobe light flashes. They can use this to study motions and vibrations. A second experiment utilizes the strobe, but also includes control of a motor with a removable disk mounted on the motor's shaft. Students can adjust the motor's speed and then adjust the strobe's flash rate. Student's can see the disk appear to stop, rotate backwards or other phenomenon. Since the disk is removable, students can prepare their own patterned disks and then observe the effect of rotation on their patterns, strobed or unstrobed. Figure 2 shows the control screen for this experiment. A third experiment is a frequency generator. By icon buttons the students can select a square, triangular or sine wave shape. Using an iconic slide bar they can control the frequency of the selected wave. Students can see both the time and frequency domain signal displays. In addition, speakers or headphones are available so that they can listen to the sound.

Figure 1. Equipment Layout

A fourth experiment allows students to play a synthesizer and again view both the time and frequency displays while listening to the notes.. By using the synthesizer, they can see and hear the difference when the same note is played by different instruments, i.e., a piano and a trumpet. See Figure 3 for the display associated with this experiment. The last experiment uses an infrared motion detector. The students can experiment with what will set off the motion monitor, such as their hand, and what will not, such as a piece of paper. This is part of an educational section on "light" waves as compared to sound waves.

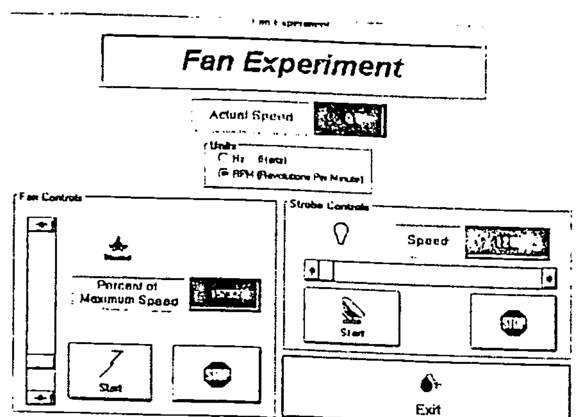

Figure 2. Fan Experiment

Visual Basic was used to develop the screens for the Windows environment. SnapMaster, a system developed by HEM Data, inc. was used for data acquisition and display. Visual Basic allows control of the Keithley, DAS 16G2, data acquisition card through SnapMaster. The DAS 16G2 also allows control of the strobe and the motor. A special interface card was designed and developed to control the signal generator.

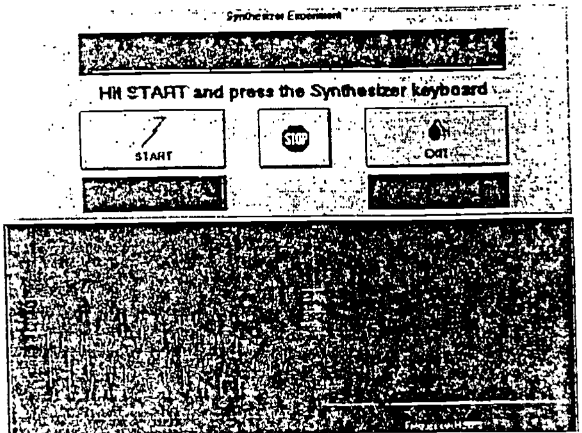

Figure 3. Synthesizer Experiment

A bus structure was designed for interconnection of the experiments. There is a standardized cable for the interconnections. Any experiment can be plugged into any of the interconnection connectors. The signal generator required a separate cable from the computer for control of its operations, however, its output goes through the standardized connector.

DISCUSSION

The objectives of the design project have been meet. An Interactive Science Experiments system which naturally allows for the inclusion of children with physical limitations on student work groups conducting experiments has been designed and developed. This work was performed in cooperation with teachers at the Detroit Academy for Science, Mathematics and Technology and staff at the Detroit Science Center.

We have installed Pointer System's Head Mouse as one access for students unable to move their arms or h·nds or who have poor fine motor control of their hands. Other access software and hardware can be readily installed as required. Access through the mouse or mouse emulation means that the students do not have to deal with complex instrumentation control. All these operations are hidden. All the students see are icons on a screen, which when activated cause very specific actions. Hence this design has significantly simplified both the cognitive and ergonomic requirements of the experiments.

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MULTISENSORY INTERFACE TO ALLOW BLIND USER ACCESS TO GRAPHICS

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ABSTRACT

As computers rely more each day on Graphic User Interfaces (GUI) to present information, computer access for blind users gets more complicated. Information contained in Graphic User Interfaces can be divided into two classes. Class I information is anything that can be completely described using words while Class II information cannot. Our main goal is to develop a nonvisual computer interface for blind users that can be used to present these two types of information. In the approach presented in this paper, a static image of the screen is transferred to a high resolution tactile medium and the image is overlaid on a touch tablet with the screen image directly mapped to its coordinates. The user can explore the tactile image while his/her finger is tracked electronically by the tablet and the position is mapped to the screen. The approach and results for this nonvisual interface are presented in this paper.

BACKGROUND

The two types of information presented by a GUI

Information contained in a GUI can be divided into two classes (1):

Class I Information: Class I information is information that is inherently verbal or that can be described using words alone (i.e. text and icons).

Class II information: Class II information is all the information that cannot be described completely with words. Examples of this type of information include many graphic images such as complex line drawings, gray-scale images, and photographs. The presentation of this information to individuals with visual impairments represents the most challenging point in our development since Class I information can be presented effectively using Braille code displays and/or speech synthesizers.

A previous attempt at this problem: System 3

An attempt to create a system that can effectively present all the information included in GUI was done by Vanderheiden and Kunz in 1991 (2). In this system, users were able to feel what was on the screen using a mouse-like device with an Optacon II vibrotactile display array embedded on it. This array size was small so that only a small area around where the cursor was on the screen was represented in the array at a time. Users explored the screen by moving the mouse around and feeling the limited tactile display under their finger. As the user moved around the screen, any text encountered was read to him/her using speech synthesis.

The greatest problem with this system was that the amount of the screen presented at any time was a small part compared to the screen image. It was also observed in field tests that most of the time the users utilized the system to explore static displays in the screen. Class II information was rarely changing so the dynamic capacity provided by the vibrotactile display was not as useful as had been thought. While the user was exploring the screen, things that changed fell into the Class I information. When encountering Class I information, the user found it easier to use a keyboard-based verbal interface rather than the tactile display.

From these observations we can support the idea that a good raised line drawing is more effective than a dynamically changing display even if the raised line drawing does not immediately reflect every change in the display (which may or may not be verbal in its nature). This is the basis for the differences between the new proposed system and the vibrotactile approach.

OBJECTIVE

The objective is to provide a multisensory interface that will allow blind users to effectively access graphical and non graphical computer information and the combination of both. This is accomplished by a combination of techniques for the presentation of class I and II information.

APPROACH

We shall call our interface the Dynamic SnapShot system. Its basic operation is as follows:

1. The user comes across an image that he/she wants to explore. This image might have been part of a paper which was scanned using optical character recognition (OCR) software to detect text.
2. The user grabs the part of the screen that he/she wants to explore.
3. The image is sent to a raised line printer where a tactile raised line picture is created.
4. The raised line image is placed precisely on a touch tablet.
5. The user feels the image on the picture while his/her finger is tracked by the tablet and the position of the finger is mapped to the screen.
6. If the person comes across any text it is read as the person moves over it. Text can be presented by using a speech synthesizer or a Braille code display.

As can be seen, the Dynamic SnapShot approach addresses the two basic problems encountered with the low resolution vibro-tactile display: 1) poor image interpretation, and 2) small amount of information presented at a time. It presents a full screen, high resolution tactile picture of the display with full access to Class I information and easier to recognize Class II images. Any part of the screen can be specified to occupy the whole table/tactile picture area so that the user can zoom into any desired graphic. A good example on how this system can be helpful is in exploring a floor plan. The user can feel the walls and architectural features of the plan while at the same time have any text in the plan spoken.

A similar approach was presented by the NOMAD audio-tactile graphics processor (3). NOMAD uses specially manufactured raised line images along with prepackaged audio and verbal information. The difference between this approach and the Dynamic SnapShot approach is that the later can provide automatic access to any image on the computer, where as the former can only handle preprogrammed images.

The SnapShot System interface consists of various input and output devices whose interactions are monitored and controlled by software programs and drivers. The input devices are a touch tablet and the keyboard. The tablet is used to track user movements when exploring the raised line image. It is also used for choosing the different options that the user has during run time, such as changing the text reading mode or choosing a screen area to explore. These options are activated by means of virtual buttons which are areas within the tablet that have been defined to call certain functions. This way the user doesn't have to memorize specific keystrokes whenever he wants to choose an option. The keyboard is used whenever the user encounters a list of text (or class I information). For example, he/she can use the arrow keys to move through the options in a pull down menu.

Two output devices are used: a speech synthesizer and a raised line printer. The speech synthesizer is responsible for providing class I information. Any text that is encountered by the user in his/her exploration of the raised line image is spoken by the synthesizer. The raised line printer provides the static image which the user feels to gather class II information. There are two ways to produce these images: wax-jet printers or swell paper. Both of these approaches are costly. The wax-jet printer uses the same principle as an ink-jet printer but applies wax instead of ink to the paper, creating a raised line drawing. Typical wax-jet printers cost $5,000 to $10,000 which put them beyond the reach of most users. Swell paper is a specially treated paper which, when run through a copier and thermal fax machine will swell creating raised lines wherever there is black toner. Swell paper costs about $1/page and its resolution is poorer than for a wax-jet image.

The SnapShot System interface was developed under MS Windows 3.1 and using Berkeley System's GUI Access Toolkit as the text recognition software. Driver and subroutines were created that monitor and control the various input/output devices to access the text in the screen as well as perform other interface options. The SnapShot program runs in the MS Windows background so that other applications and programs can run normally.

USER TESTING AND RESULTS

Several persons who are blind experimented with the Dynamic SnapShot system prototype. The tests that were done were mostly qualitative and aimed at comparing SnapShot with previous interfaces experimented with by the users. They were asked to explore several images that contain a certain level of Class I and II information such as floor plans, maps, and charts. As had been observed with System 3, zooming into small objects greatly helped in the visualization of a complex image. This is especially true given that the method currently being used for obtaining raised line images is not of the best resolution. Users were able to notice and find things they did not notice on an unzoomed image.

Perhaps the most significant improvement was the overall resolution and bandwidth presented by a whole page image as opposed to a small vibrotactile display. The users felt more active in the exploration (both hands may be used) and had a better idea at all times of where they were located in relation to the complete picture. All this resulted in their being able to gain a broader view of the image quicker .

Even though screen text reader programs are widely available, users found the system very helpful in learning about text format and text position in documents. Text documents where position is important, such as a table, can be better understood by knowing the position of each piece of text relative to others. Users found that access to a table was easier using the system because using a text reader they may loose the sense of their overall position. They found specific items in the table with more ease.

There are commercially available systems that include pre-drawn images along with software to explore them (NOMAD audio-tactile graphics processor). However, they can only work with the provided images. New images would have to be produced and programmed into the system. The advantage of the Dynamic SnapShot approach is that it offers users the ability to explore any image that is already available in the computer by just printing it and exploring it on top of the tablet.

CONCLUSION

The presentation of graphic images to persons who are visually impaired is an interesting and challenging topic which deserves more research. With more information being provided electronically through computers and more of this information being provided in graphical form, ways to universally present computer information are needed. We have presented and implemented an approach that allows blind users to access both Class I and Class II data in a document/image that contains these types of information. This approach involves the exploration of static images by using raised line images placed over a touch tablet. The system showed to be an improvement over a previous method aimed at presenting this information dynamically. It gave users a better resolution and broader view of the image allowing them to interact faster and more actively to what is happening on the computer.

We are a long way from having a practical and inexpensive full page tactile display available. Even when such a display is available, it is only an output device which does not give the computer any information about the user's actions. In the meantime, the solution offered by the Dynamic SnapShot system, in addition to any options that may enhance a blind user's perception of a graphical image, is practical and relatively inexpensive. An approach such as the one we have implemented holds great potential for reducing some of the barriers of accessing graphics for blind people.

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THE DESIGN OF A FOOT ACTUATED CONTROL INTERFACE

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Although the foot is considered to be a viable control site for assistive technology, little exists in the way of interfaces specifically designed for this site. This paper describes the design, development, and fabrication of a foot actuated switched joystick type of interface. A prototype was developed that is compact, rugged, and durable. The device performed well in testing and could be mass produced. The design is intended to be used to operate augmentative communication devices, environmental control units, or power wheelchairs.

Introduction

This paper describes the design and development of a foot actuated joystick type of control interface. This device is intended to be used by wheelchair users whose optimal control site is the foot. These individuals may lack the strength or coordination to use the arms or hands effectively, as a result of conditions such as cerebral palsy, multiple sclerosis, or muscular dystrophy. Behrman (1990) lists fifteen conditions for which a wheelchair might be required, but control of the feet might still be possible. Cook and Hussey (1993) suggest that the foot is preferred control site after the hand and head.

Unfortunately, there is little available in the area of foot operated interfaces. A search of the recent literature, including relevant journals, catalogs, and conference proceedings, revealed little on joysticks and less on foot activated devices. Several suppliers offer switches that could be used as foot controlled interfaces, but these are mainly adapted hand switches instead of devices specifically designed for the foot.

Hand, finger, and chin operated joysticks are common interfaces for assistive technology, but no foot operated equivalent seems to be available. The goal of this project was to develop such an interface, to allow foot operation of power wheelchairs, environmental control units, and augmentative or alternative communication systems.

Design

The design team consulted biomechanists, therapists, and potential users to ensure that the design would meet the intended user's needs. As mentioned above, a review of the literature in this area was also performed. With this background, the team was able to establish the requirements for the design. It was determined that the device should be small, compact, rugged, and weather resistant. It should incorporate a five switch array (four directions plus a select switch), operate without external power, and provide tactile feedback to the user.

To meet the design criteria mentioned above, the maximum size of the device was set at six inches square and one inch thick. These values were determined from measurements of several types of wheelchair footrests. The thickness requirement is important because some wheelchair footrests are adjustable in only one or one half inch increments; the device needs to be an even inch thick so that the top surfaces of the footrests can be aligned after the device is installed.

The requirement that the interface operate without external power necessitated a switched type of joystick instead of a proportional control, but allows the device to be used with communication devices and environmental controls which do not provide power.

A mock-up was constructed to determine how much force the typical user could be expected to exert, and how much travel was needed to provide adequate tactile feedback. Testing with this initial prototype revealed that spring constants of about 10 lbf/in were appropriate, and that one quarter inch travel was sufficient. This testing also revealed an unanticipated problem: in use, the user's foot could and would often twist, resulting in rotation of the slider. The slider, or movable part of the mock-up, was square. When twisted, it jammed the springs and allowed them to escape from their proper positions.

The final design, shown in Figure 1, makes use of the information learned from both the research and the initial prototype. The user's foot rests on top of the device, on the plate shown in the side view. The plate is connected to a cylindrical slider (shown separately in Figure 2) which moves in the base. The circular design of the slider allows it to rotate with the user's foot, and eliminates the problems seen in the mock-up.

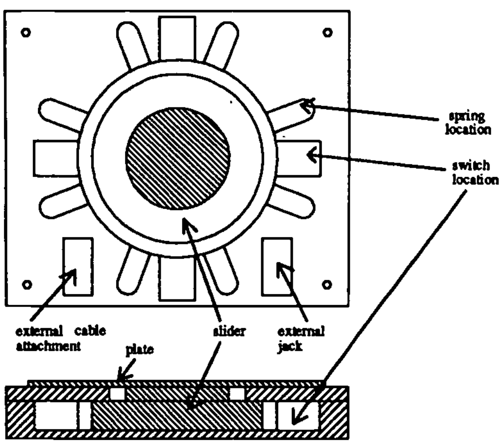

Figure 1
Cutaway of Base, Cross Section of Side

The cutaway top view (Figure 1) shows the locations of the eight springs and four switches. A spring is placed on either side of each switch location. Sufficient displacement of the slider results in compression of two of the springs and activation of the adjacent switch.

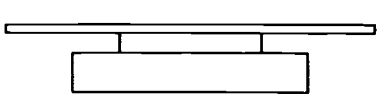

Figure 2
Side View of Slider

Several options were considered for the select switch, including pull up activation, push down activation, and a heel or toe switch. Each of these choices had drawbacks. Push down activation, for example, had the undesirable drawback of possible unintentional selection when the user's chair went over a bump. The design includes a switch jack so that whatever type of switch best meets the client's needs can be used. The base of the device includes tapped holes so that a switch can be mounted directly to it.

The top of the box, shown in Figure 3, serves to restrain the slider. In addition, it was designed to be strong enough so that it can easily withstand the force of someone standing on the device. The top transfers the force away from the slider into the base. The bottom of the slider never feels the force of the user's weight, which helps reduce wear and friction, making the device easier to use and more durable.

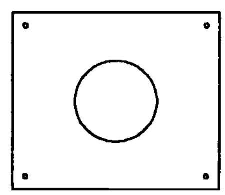

Figure 3
Top

The foot interface is equipped with a cable and DB-9 connector, so that it is fully compatible with standard joystick plugs. The cable can be routed up the footrest structure to the appropriate device.

Fabrication

Several types of plastic were used for the prototype. Plastic was chosen over other materials because it can be machined easily and will not corrode. Other advantages of plastic include the fact that it is lighter than metal and is electrically non-conductive. The base and slider were machined from compression molded acetyl. This material is rugged, machines well and will hold tolerances. The top plate (shown in Figure 3) was made of 1/4" Teflon which provides a low friction, strong, weight bearing surface for the plate. The plate was made of PVC sheet. Fabrication of the prototype was done on a CNC milling machine using the CAD design drawings.

The switches chosen were cantilever arm micro switches typically used as the select switches in a computer mouse. These switches are very durable and are mounted so that the metal arm will not be fatigued when the switch is activated. The switches were mounted in the base using tapped holes and screws so they can easily be replaced in the event of failure.

A small slot was machined around the perimeter of the switch and spring array to give a path for the routing of the wire to each switch.

An adhesive backed no-slip abrasive material was used for the top surface of the slider. This material is typically used for walking surfaces on stairways and ramps and provides the user with a good gripping surface for most shoe types and weather conditions.

Discussion

The finished prototype meets all of the design criteria, and performed well in testing. It is small enough to be bolted to a standard footrest. Tapped holes are provided on the underside of the base for this purpose.

As currently configured, only one switch can be activated at a time. This helps prevent unintentional selections. Some applications might require multiple switch activations, or a diagonal selection. The design could be altered for this use by adding four more switches in the spaces available.

This design could easily be produced commercially. In production, the entire unit could be injection molded. The device could be supplied with stiffer or softer springs to accommodate user preferences and abilities. Materials for the prototype cost under $50.

The prototype is built to withstand the forces and abuse encountered in normal use, including transfers. The design of the slider and plate helps to keep dirt out of the mechanism. All of the components can be replaced if worn or damaged. The exceptional strength and durability of this design might make it desirable for use as a hand joystick (equipped with a knob instead of a plate) for very strong or spastic users who would destroy a conventional joystick.

Conclusion

A prototype foot actuated interface was designed and built. The unit is small and rugged. It performed well in testing. It should be possible to manufacture the unit easily and affordably.

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Switch Activated Dispenser for Packaging

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ABSTRACT

This was a collaborate project which included students from the Electrical and Computer Engineering Department at Wayne State University, and staff of Ashcroft Center, a school with about 120 students, most of whom are labeled Severely Mentally Impaired or SMI. The project was designed to allow SMI students to perform packaging tasks. A Selectivend vending machine was gutted, reserving only its trays and motors, and customized to provide switch activated dispensing for the packaging jobs. Objects for dispensing included small mints to toothpaste boxes. ADAMLAB's Lynx provided an auditory feedback in addition to the visual display of the active trays and falling objects. The dispenser system supports a single user mode and a two user mode wherein students must cooperate in order to complete the task. The system has been operational for over six months. It has been successfully used for a variety of packaging tasks. It has allowed physically limited students to participate in numerous packaging tasks within the workshop environment. The device has decreased the need for one-on-one staff intervention.

BACKGROUND

This project was done in collaboration with the staff of Workshop Tool!, an adaptive Workshop run by Ashcroft Center, which in turn is operated by the Wayne County Regional Educational Service Agency (WC RESA). WC RESA is an intermediate school district providing direct services to 34 local school districts in southeastern Michigan. Ashcroft has about 120 students, most of whom are labeled Severely Mentally Impaired or Severely Multiply Impaired.

OBJECTIVES

The project was designed to allow Workshop Tool! students who have severe physical limitations that prevent them from being productive in a "standard" workshop to perform tasks along side their more able-bodied peers. Packaging tasks were selected as the target task group. The workshop environment required flexibility, and variation in operating modes and control. Items to be packaged ranged in size from small mints to toothpaste boxes. The system was required to operate under single switch control. Staff wanted the system to support one or two switch dependent students. Multiple modes of feedback were requested since the student's performance improved with more and varied feedback.

METHODS

In order to accommodate the wide variety of items, a SelectIvend vending machine (Model 20, circa 1940) was gutted and its dispensing motors, and dispensing trays retained. The original relay and push button / coin based control mechanism was replaced by a microprocessor control system. The system was also designed to interface with ADAMLAB's Lynx voice output unit, for audio feedback. Staff can easily input four customized messages into the Lynx for playback when activated. Adapting tray insert mechanisms were used to allow the dispensing of small objects. The original Model 20 case was replaced by a customized enclosure with a clear plastic door which allow the students to see the trays rotate and watch the objects fall from the trays through a chute into the collection bag or bin. This provides additional feedback to the students. See Figure 1.

Figure 1. Dispenser

The dispenser has nine dispensing trays and associated motors. There are three different tray sizes to accommodate different sized items, from as

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small as 1 inch in diameter to 10 inches in diameter. During job setup, staff can select, by way of ninecontrol panel switches, the specific trays to be used in that job. Each switch is labeled and an LED underneath the switch is illuminated to indicate tray selection.

In addition to tray selection, staff can specify the number of items required to fill a bag or bin. A thumbwheel switch labeled "Maximum Number of Items" is used for this selection. This maximum number is used by the control computer to activate the audio feedback completion message

At setup staff can also select the mode of operation, i.e., one or two users. Mode 1 is designed for a single user. In this mode, activation of the controller switch starts the dispensing process. There are only two Lynx messages; encouragement and completion. Mode 2 is designed for the interaction of two users. In this mode the students must cooperate in order to complete the packaging task. Each user has a control switch, but only one switch is active at a time. The system prompts the first student and activates his/her switch. That switch must be operated for an item to be dispensed. After dispensing, there is a second audio prompt for the second student to hit his/her switch. The first switch being deactivated and the second switch activated. In either case, nothing happens unless the appropriate student hits their switch. If too much time goes by without a switch hit, (this interval under staff control) the Lynx issues a prompting message.

The dispensing system is powered by two separate power supplies; a 24 volt source for the motor assembly, which is isolated from the control unit's (5 volt) supply. The dispenser consists of nine motors controlled by a Motorola 68HC11EVBU board. Selection of a motor is controlled by a switch located on the control panel. The switch provides a signal to the Motorola 68HC11EVBU upon system initialization. From a control perspective, the trays and their associated motors are uniquely identified by a number. The objects are dispensed starting from the smallest selected number to the largest selected number.

The nine motor controlling switches are connected to the Motorola controller through a 25 pin RS232 port and jumper cable. The Motorola 68HC11EVBU interfaces with the tray motors by way of reed relays. This interconnection isolates the controller from the motors. The relays serve to trigger motor movement as only a switch closure is required. Similarly, the control board is isolated from the Lynx audio feedback unit through the use of 4 relays, one relay for each of the four messages.

The control panel is the focal point of user interaction. The control box houses the Motorola 68HC11EVBU, four audio relays (for control of the Lynx), and user input and option switches. The control box is connected to the motor housing via a RS232 25 pin port. The control box was designed to offer a wide variety of operating conditions. All operating options are configured using the control panel.

In addition to the tray selection switches, Maximum Number of Items switch and Mode switch the control panel contains the system's power switch and system on-off indicator light, a reset button which terminates operation and resets the system's controller. This controller is shown in figure 2.

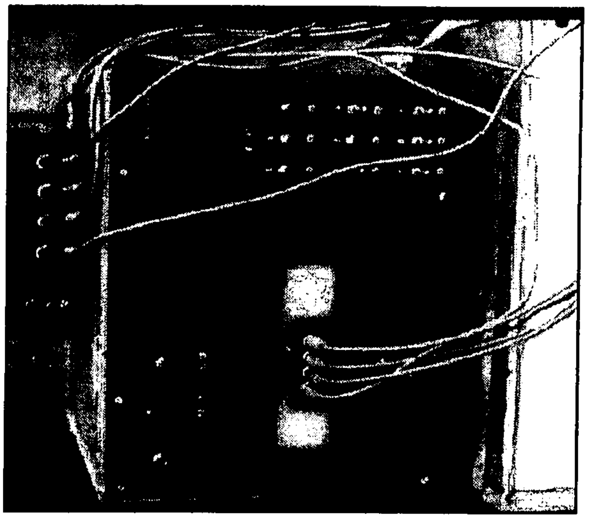

Figure 2. Controller

Assembly code was used to program the Motorola 68HC11EVBU to control input and output flow. A program was written to ensure proper control of the dispensing unit. The code was written in a modular fashion. Major program modules were written for:

- PORT E - Input read port for Mode and # of Items
- PORT C - Input read port for Motor Enable Switches 1-8
- PORT A - Input read port for User Switch 1 and 2 Output port for ADAMLAB's Lynx Audio Messages
- PORT B - Output port for motor activation

USER_1 - Program routine to activate Mode 1
USER_2 - Program routine to activate Mode 2
VOICE - Voice routine to provide audio prompts
DROP - Motor activation routine
DEL_50M, DEL_1S, DEL_4S - Relay and motor delay routines

The design of the customized dispenser case took into consideration user safety, as well as the needs for ease of loading, cleaning, and a visual display of events for user feedback. The trays and motor assemblies were mounted in a chaise with a clear plastic front opening door. This allowed easy access for loading and cleaning and provided the students with a clear view of the tray's dispensing operations. The original SelectIvend tray and motor mounting and guide rail assemblies were retained in the customized design. This allows for removal of the tray/motor assemblies from the front of the unit. A new wiring harness was fabricated and ran from a connector on the side of the chaise to connectors on each of the three tray/motor assemblies. The motor housing, control panel, and voice units are all detachable this allows the units to be kept out of reach of the students and provides flexibility for placement of the units depending on the work site environment. Figure 3 shows a student hitting a switch. Figure 4 shows an object falling from the chute into a bag.

Figure 3 Hitting a switch

DISCUSSION

The Switch Activated Dispensing System has been operational for over six months. It has been successfully used for a variety of packaging tasks. The system satisfied staff requirements for flexibility, in terms of the size and number of items to be packaged. The system allows for one or two switch dependent users. It provides auditory feedback along with the visual display of items falling into the collecting bag or bin, thus providing multiple performance feedback for the student.

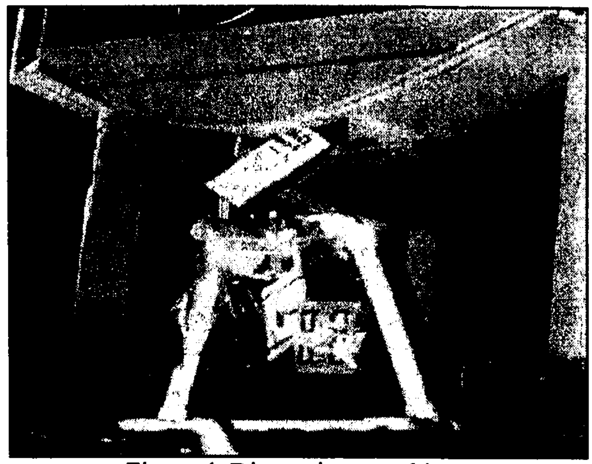

Figure 4. Dispensing an object

The device has allowed physically limited students to participate in numerous packaging tasks within the workshop environment. The device has decreased the need for one-on-one staff intervention. The system's capabilities have allowed students the freedom to dictate the success or failure of their efforts on the job. This device has proven itself to be a viable option for those individuals without hand and arm volitional control.

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THE DESIGN OF A HYDRAULICALLY POWERED ELEVATING TOILET SEAT

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ABSTRACT

The design of a power elevating toilet seat that aids the user in getting into and out of the seated position is presented. This device is unique and differs from currently available elevating toilet seats in several ways; most importantly, it is powered by pressurized water from the existing water line in the bathroom. The device offers an inexpensive, safe and completely functional alternative to other assistive toilet seats. A prototype has been constructed and tested. This paper describes the development and design of the device, as well as its potential as a consumer product.

BACKGROUND

For persons with strength and/or mobility limitations, lowering onto and rising from the toilet seat may be difficult. The utilization of appropriate assistive technology can make this task easier to perform. Unfortunately, however, 'appropriate' technology is not always available, and the consumer must therefore settle for an assistive device which may not be completely adequate. For example, a device that is commonly used to facilitate getting on and off the toilet is the "elevated seat," a cushioned toilet seat which increases the height of the sitting surface to a level many inches above normal. The drawback to this design is that the user, when on this seat, is no longer in a natural seated position(i.e. partially crouched). This can lead to discomfort and/or increased physical exertion, both of which are undesirable, especially since in many cases the user is weak and prone to injury. In response to the need for more appropriate assistive toilet seat technology, several manufacturers have developed power elevating toilet seats; these utilize a user controlled actuating device that actively raises and lowers the seating surface so that the user can remain in a natural seated position.

STATEMENT OF PROBLEM

Although all currently available power elevating toilet seats are relatively similar in design(e.g. they utilize electromechanical actuating devices), no two operate identically. With some, the toilet seat merely translates up and down, while with others the seat tilts as well. Improvements that can be made to these types of designs include: the use of a hydraulic actuating system, since a nearby source of pressurized water exists (the supply line to the toilet tank); and the reconfiguration of the lifting mechanism so that the seat not only tilts and translates vertically, but also translates toward the user (i.e. the seat moves forward to meet the user as opposed to the user leaning back to meet the seat).

DEVELOPMENT

Presented here is the design of a power elevating seat that incorporates the aforementioned changes, in an attempt to enhance the performance of the device. The development of this design, and the construction of a corresponding prototype were completed as a project for an undergraduate, senior level mechanical engineering design course. The project was completed in one semester, with a budget of seventy-five dollars. The goal of the project was to develop a product that meets the following criteria:

1. functional
2. safe
3. inexpensive
4. convenient and retrofittable...
   a. can be attached to any toilet base
   b. easily assembled, installed and operated
   c. can be used by anyone
5. cosmetically appealing

To this end, considerable attention was given not only to the engineering aspect of the design, but to human factors as well. Since the device has been designed specifically for physically challenged persons, it should certainly meet their needs. For this reason, efforts were made to create a device that is easy to operate, comfortable and safe. As one example, the manual actuator controls (i.e. levers) have been placed in an easy to reach place (on the handle), and are easy to use so that persons with weak and/or non-dexterous fingers should have no problems. Further, attempts were made to develop an ergonomically appropriate product; as such, body dimensions and postures were taken into account throughout the design process (1,2).

DESIGN

The most attractive feature of the hydraulically powered elevating toilet seat, shown in figure 1, is its retrofittability; it can be easily attached to almost all standard toilet bowl bases. Only two attachments are necessary: the mounting platform is bolted to the toilet base using the plastic bolts that are normally used for the seat cover hinge; and the inlet hose connects to the water supply pipe that provides pressurized water to the toilet tank. Other than these, there are no attachments between the device and its surroundings. Instead, all components are secured to the mounting platform. The toilet seat, which is not hinged at the rear so that it can both rotate and translate forward, is connected to the platform via two pairs of linkage bars, one pair of which is connected to a pair of piston rods. These pistons, together with the actuators within which they translate, are part of the hydraulic apparatus, which itself is supported by a platform that is secured to the main mounting platform by means of a mounting flange. Power for the actuators is supplied by pressurized water from the existing water line. The user activates the hydraulics through a lever located on the handle. There are two levers, one is used to raise the seat, the other to lower it. Each lever is mechanically linked to a ball valve located at a hydraulic inlet or outlet port. The ball valve handles are each equipped with a spring in order to facilitate easy closure of the valve. To raise the seat, the user turns the lever located on the right handle, thereby opening the inlet ball valve. Pressurized water then enters the actuating cylinders, thus extending the pistons, which in turn cause the linkage mechanism to raise the seat. Releasing the lever returns it to its original position and closes the spring loaded ball valve. To lower the seat, the user activates the outlet ball valve through the lever located on the left handle. Under the user's weight, the seat returns to the level position as water is expelled from the hydraulic actuators and routed to the toilet tank (so that water is not wasted).

EVALUATION

Force analysis has been carried out on both the linkage bars and hydraulic actuators. The actuators were analyzed in order to determine what magnitude of force the pistons can provide. Assuming water pressure from the city line to vary anywhere from 20 to 70 PSI, the force available from each piston ranges from 35 to 123 lbs. A mechanical advantage exists in using the linkage mechanism so that each piston has to support only approximately one-third of the user's weight. As such, in the worst case, in which water pressure is only 20 PSI, the hydraulics can support 210 lbs.

The linkage bars were analyzed in order to determine whether or not they would mechanically fail under the expected operating loads (i.e. user weight). For a variety of linkage bar materials, including steel and aluminum, calculations indicate that the bars will not fail due to either bending or axial compressive stresses.

In addition, testing of the prototype provided insight into the performance of the device, and indicated areas that may require modification. It functioned well (i.e. it successfully met all of the specified criteria), but not as well as expected. In particular, the lever with which the user activates the actuating mechanism presented some problems. Discussed in the next section are improvements that should be made to a second generation prototype of the device.

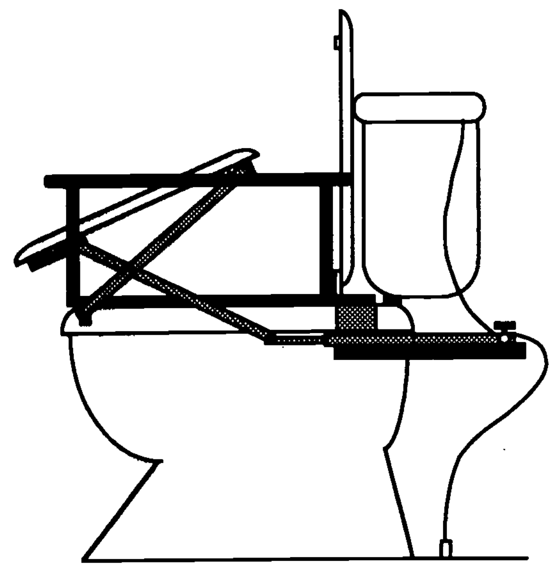

Figure 1...schematic side view of hydraulically powered elevating toilet seat in raised position.

DISCUSSION

In its current form, this hydraulically powered elevating toilet seat has potential as a marketable item. The fact that it may be constructed from off-the-shelf parts is attractive to the manufacturer because the device can be produced at relatively low cost. This translates into savings for the consumer. Further, the retrofittability of the product will save the consumer time as well.

Improvements that can be made to the device in order to enhance its marketability include:

1. reconfiguration of the hydraulic lines that feed the actuators, so that the device takes up less space behind the toilet base; this would increase its retrofittability (i.e. it could then be used with any toilet base, not just those with adequate space).

2. construction of the mounting platform and all of its attachments as a single piece (a molded polymer, perhaps); this would reduce consumer assembly time.

3. redesign of the mechanism by which the user initiates motion of the seat. This is necessary because it is essential that the device be easy to operate.

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A NEW SWITCH ACTUATOR DESIGN THAT ENHANCES PROPRIOCEPTIVE FEEDBACK IN THE USER OF LIMB POSITION

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ABSTRACT

This focus of the present work is the development of a new switch actuator design that enhances proprioceptive feedback in the user of limb position. In particular, the author proposes an innovative extension to the trackball concept: a spring-return-to-center half-trackball actuator mechanism. A key feature of the design is that it stimulates the user's proprioceptive feedback system in direct proportion to the current position of the actuator. In addition to providing high-quality feedback of actuator position and switch status, the mechanism also eases the loads put on the user's leg muscles in operation in two important ways. First, by effectively acting as a giant "ball bearing," this type of actuator requires very little force to operate. Second, the placement of the half-trackball element relative to the foot effectively constrains the directions of the forces required to operate the actuator within an envelope of comfort for the user.

INTRODUCTION: THE "INTENTIONALITY GAP"

Over the last several years, there has been a growth in awareness on the part of society of the needs of people with severe motor disabilities. Such disabilities can be the consequence of cerebral palsy, head trauma, or other serious insult to the body. Arguably, the most pressing problem confronting individuals in this group is their impaired ability to interact with their environment. The most significant consequence of this situation is the resulting gap between the desires of people with severe motor disabilities to interface with or to manipulate the world around them, and the realization of those desires. The author has dubbed this situation the "intentionality gap."

Ultimately, to close this "intentionality gap," a means whereby such individuals can effect changes in the world about them and perhaps change their relationship to it must be provided. Current technologies for bridging this gap include powered wheelchairs, augmentative communication systems, and environmental control systems. A key component in the successful implementation of all such systems is a reliable, easy to operate user-interface designed with the special needs of this user group in mind.

BACKGROUND

This focus of the present work is the development of a new switch actuator design that enhances proprioceptive feedback in the user of limb position, and hence that of the switch's status. The outcome of this project for the author has been a deeper understanding of these systems, as well as the development of a working prototype. The design of this actuator mechanism was prompted by the need to provide a certain person with an easy to use, foot-activated, multi-channel input device for use with both a power wheelchair and an augmentative communication system. The particular individual that this switch actuator system was designed for is a six and one-half year old boy with severe cerebral palsy. This person has limited command of his limbs, his legs and feet being most controllable. Although designed in response to the needs of a specific individual, the author feels strongly that the new actuator system would be widely applicable to the needs of other individuals with similar disabilities.

STATEMENT OF THE PROBLEM

After analyzing the user's needs and capabilities, as well as the dynamics of his past interaction with various switch devices and joysticks, it became apparent that it was difficult for him to determine the current position of switch actuators, and therefore the associated switch's activation state, because of a lack of "reference grounding" for his proprioceptive feedback system. In short, he could activate the mechanisms, but could not tell reliably how far or in which direction he had pushed the device's actuator. One example of this is that of his difficulty in operating joystick-type actuators. In order to operate such an actuator, he must lift his foot and place it on top of the handle. The act of lifting the leg to place the foot on the handle causes immediate loss of reference contact with his footrest, resulting in wild gyrations as he tries to locate and make contact with the handle. As one might expect, when contact does occur the control is forced into a full-on state. Frequently, this causes the him to break contact with the handle and cycle through the process again. An unsuccessful attempt was made to correct these problems by conventional means, including the use of guards, varying the actuator's placement, force required for operation, and electronic damping.

An extensive, unsuccessful search for appropriate switch actuator devices, combined with unsatisfactory trials of many available devices convinced the author that a new switch actuator design was needed to solve the user's input control problem. In particular, presently available multi-way switch mechanism actuators do not provide adequate feedback to the user of the current position of the switch. The most widely used multi-way switch actuator mechanism in this context, the joystick, has a number of limitations when applied as a foot-operated device, the most significant of which being the difficulty of determining its current position when in use. This is not surprising, especially considering the fact that joysticks were developed for operation by hand.

DESIGN OBJECTIVES AND CRITERIA

The principal objective of this effort is the design and development of a foot-activated, multi-channel input device for use with both a power wheelchair and an augmentative communication system, that provides the user with direct feedback of the actuator's position and switch's state. It should be noted at this point that the choice of a physically operated actuator, rather than some other more exotic means like EMG or eyegaze detection, is dictated primarily by the intended user: an individual with impaired, but not absent, motor function. In addition, physical coupling has the advantage of direct feedback, lower cost, simplicity, and ease of integration with existing systems. As most systems that it is intended to operate with provide on/off interfaces, the unit should provide on/off rather than proportional operation. Binary operation was selected both because it is significantly easier to implement than proportional control as well as because it does not significantly limit its functionality.

DESCRIPTION OF THE DEVICE

To address these problems, the author has developed an innovative extension to the trackball concept: a spring-return-to-center half-trackball (see Fig. 1). A key feature of the new design is that it stimulates the user's proprioceptive feedback system in direct proportion to the current position of the actuator. To get an idea of the quality of feedback provided, the reader can experience a simulation of it by placing a tennis ball on the floor and using his foot to move it around in a small circle. This type of feedback is markedly different and more effective than that experienced by the user of other switching systems (i.e. joysticks, wobble switches, etc.).

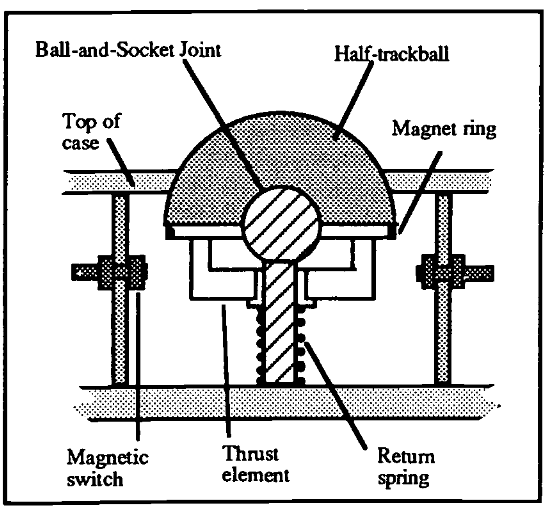

Figure 1: Actuator Detail

In operation, the actuator mechanism functions by "rolling" under the user's foot in response to the directional force applied by the user, thereby changing its position relative to the user's foot. This change in position relative to the user's foot is directly correlated to the current position of the switch. In order to insure that this feedback remains in proper phase with the switch's state, an innovative spring-return-to-center half-trackball system was developed. Removal of the user-applied force results in the immediate return of the half-trackball to the center-off position, guaranteeing a known state upon next activation.

In addition to providing high-quality feedback of actuator position, the half-trackball mechanism also eases the loads put on the user's leg muscles in operation in two important ways. First, by effectively acting as a giant "ball bearing," this type of switch requires very little force to operate. Second, the placement of the ball element relative to the foot effectively constrains the directions of the forces required to operate it within an envelope of comfort for the user.

As one might expect, a number of designers and researchers have worked in the area of switch design. The range of commercially available switch designs is astounding. As far as switches designed especially for use by individuals with motor disabilities, there are various types of joysticks, sliding plate devices [1], force sensing devices, EMG sensor operated switching systems, sip-and-puff systems, and many others. However, to the best of the author's knowledge, there are no systems in existence like the one developed in this work.

DESIGN AND FABRICATION

In the development of a prototype system such as the present work, the process of design is closely linked with that of fabrication. This is because many design parameters must be determined empirically (that's code for "trial and error). In the present case, a number of designs were considered before settling on the present one. In fact, the initial idea was for the development of a "roller" actuator that would provide three-way operation: forward, center-off, and reverse. A prototype was even constructed to test the concept. This approach has great promise but was put on hold temporarily because it did not meet the intended user's needs. With respect to attachment mechanisms for the half-trackball, joints other than the ball-and-socket joint were considered. Before settling on the ball-and-socket joint, a gimbal mounted ball was designed and fabricated.. Unfortunately, the gimbal mount constrained the motion of the ball in ways that made it feel "funny" when operated.

A large number of design constraints were evaluated during the development process. At the macro level, some of these included: user needs, user safety, aesthetic appeal, size, weight, and cost. At the micro level, factors considered included: force needed for switch element activation (the relevant factors being return-spring stiffness and hysteresis, ball/socket joint friction, thrust-plate/thrust-element friction, and user/switch dynamics); impact resistance of case; and switch type selection, including cost, reliability, and adjustment. After magnetic non-contact switching was selected, further considerations included switch element placement and adjustment, magnetic force required for operation, magnet selection and placement, and magnetic hysteresis effects. Size and geometry of operation element (the half-trackball), including angular travel, effective diameter, and projection distance from mounting surface were estimated based on the anticipated user's size. Ease of assembly and disassembly, including position and number of fasteners, absolute and relative placement of interior components, and prevention of relative movement on disassembly between operating elements and their adjustment benchmark surfaces were also taken into consideration. Finally, return-to-center action, including user feel, operation deadband, linearity of operation, speed of operation, and travel limits were important considerations.

The actuator activates the magnetic switches by way of a ring of high-strength magnets placed around the base of the half-trackball. When the ball is moved, it rotates symmetrically about the ball and socket joint, bringing the ring of magnets within the operating envelope of one, or at most two, of the magnetic switches. In this manner, one can achieve coupled motion control for a power chair (e.g. forward/left or reverse/right pairings). The range of travel is 30 degrees off-center in any direction, the half-trackball being free to rotate as necessary.

MANUFACTURABILITY

Significant effort has been expended in the design of the unit to make it easy to manufacture and service. Lexan sheet was chosen for construction of the prototype, principally because of its transparency. Additional factors included its excellent impact resistance, moderate cost, and good machinability. In commercial production, the author anticipates that most of the components would be produced by injection molding instead of being fabricated from Lexan sheet. The anticipated cost of commercially produced units is approximately $400, a moderate cost in comparison with the units it is intended to interface with.

The main operating adjustment needed in the field consists of setting the return-to-center spring force, a relatively easy process involving the placement of shims. Mounting holes have been provided, as well as standard electrical interface connections.

SAFETY

The unit is inherently safe. There are no exposed voltages. Great care has been exercised to eliminate sharp edges and pinch points. Also, the unit is fabricated from high-impact plastics.

DIRECTIONS FOR FUTURE WORK

Several things come to mind with regard to extending and improving this design. First, and perhaps most useful, would be provision of proportional output signals for use by power wheelchairs. This is a non-trivial modification, given that it must guarantee position-proportional and return-to-center functionality using non-contact sensing. Another modification would be the inclusion of a small projection or button in the center of the half-trackball to enhance position feedback to the user. One might also consider slightly abrasive textures for the half-trackball to increase tactile feel and to increase foot to actuator friction. Other materials would be expected to be used in a commercially produced version of this device. As such, research into optimal choices along these lines is indicated. Finally, although none of the components are sensitive to moisture, one might want to seal the unit from intrusion of environmental elements for other reasons.

CONCLUSIONS

The author believes that this device can be applied to meet the needs of many individuals. The author further believes that users will like the new switch actuator, as it provides them with stimulation of their proprioceptive feedback system in direct proportion to current position of the switch. The system is currently undergoing testing. Early results are very encouraging.

ACKNOWLEDGMENTS

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Whitaker Student Scientific Paper Competition

1994 Whitaker Student Scientific Paper Competition

On the following pages you will find the five award winning papers for the first Annual RESNA/Whitaker Student Scientific Paper Competition. These awards are supported through the generosity of the Whitaker Foundation. The purpose of the Student Scientific Paper Competition and Awards is to encourage and promote student participation in high quality research related to the fields of rehabilitation engineering and assistive technology. The competition is intended to encourage students from a variety of disciplines to address issues in the field of assistive technology and submit papers for presentation at the RESNA Annual Conference. This competition is based on scientific merit of the reported research and is structured to be distinct from and complimentary to the Easter Seal Student Design Competition.

The winning papers in the Whitaker Competition were all presented in a special session at the RESNA '94 Conference. This session is unique in that it provided a forum which, in addition to highlighting student research activity, brings together papers on diverse topics for presentation. It is our hope that this will set an example for other sessions at our annual conferences where RESNA members from a wide range of disciplines and backgrounds can interact on a scientific basis.

There were a total of 18 papers submitted for the competition this year. Members of the Student Scientific Paper Competition Committee scored each paper after careful review based on the following criteria:

- General quality of the writing and presentation.
- Clear statement of hypothesis or research issues to be addressed.
- Choice and description of appropriate methodology.
- Presentation of the results.
- Discussion of the results and their significance.

The reviewers faced very difficult decisions in choosing the five winners as more than half of the papers were deemed meritorious. In the end the five winners were chosen based on average scores from the six reviewers. Very careful consideration was given to avoid any potential conflicts of interest by (1) blinding the reviewers to the authors and their institutional affiliations [to the best of our abilities], and (2) choosing reviewers who had no association with any of the authors or papers.

While the number and quality of papers submitted this year were very gratifying, I hope to see a continually increasing number of papers in future years. The goals for this competition are to promote student participation in assistive technology research, improve the quality of scientific and engineering research in our field, and provide a new interdisciplinary forum within RESNA. With the help of RESNA members I am sure that we can achieve these outcomes.

RESNA wishes to thank the Whitaker Foundation for its support, the judging committee for a difficult job well done, and all the students who submitted papers. I invite students to start planning their research for submission to the 1995 RESNA/Whitaker Student Scientific Paper Competition.

Simon P. Levine, PhD
Chair
RESNA/Whitaker Student Scientific Paper Competition

THE EFFECT OF A WORD PREDICTION FEATURE ON TEXT GENERATION RATE

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Abstract
This study examines how use of a word prediction feature affects text generation rate performance. Fourteen subjects transcribed text with and without a word prediction feature for seven test sessions. Eight subjects were able-bodied and used mouthstick typing, while six subjects had high-level spinal cord injuries and used their usual method of keyboard access. Use of word prediction decreased text generation rate for the spinal cord injured subjects and only modestly enhanced it for the able-bodied subjects. This suggests that the cognitive cost of using this word prediction system largely offset the benefit of the keystroke savings achieved by these subjects.

Background
Word prediction is an effective way of reducing the number of selections required to generate text. This benefit in keystroke savings provides decreased motor requirements. However, it also exacts a cost in the additional cognitive and perceptual activities that are necessary to navigate the word prediction list [1,2].

The available data on user performance with word prediction suggests that the time required for these additional processes at least partially offsets the benefit of keystroke savings [3,4,5,6,7]. The keystroke savings reported for users of word prediction is fairly large, averaging 40%. However, the overall improvement in text generation rate for these users ranges widely; while some users enjoyed substantial improvement relative to letter-by-letter spelling, others improved only marginally or even decreased in rate. This provides indirect yet strong evidence that the cognitive time cost associated with word prediction can have a major impact on user performance. The wide range of reported improvements also suggests that this cognitive cost is highly variable, and the reasons for this variability need to be better understood.

Research Questions
The goal of this paper is to provide further insight into how the trade-off between decreased motor and increased cognitive loads affects text generation rate during use of a word prediction system. Performance will be measured under a range of usage conditions, to help determine the role of factors such as the characteristics of the system, the user, and the way in which the user employs the system. Ultimately we would like to define the conditions under which word prediction improves text generation rate and those under which it does not.

Methods
Subjects. Fourteen subjects participated. All shared the following characteristics: at least some college-level education; high familiarity with the standard keyboard; no significant prior experience with word prediction; and no cognitive, perceptual, or linguistic impairments. Eight of the subjects were able-bodied, while the remaining six had spinal cord injuries at levels ranging from C4 - C6.

Systems. The "Letters-only" system involved letter-by-letter spelling on a standard computer keyboard, and the "Letters+WP" system used single letter entry augmented by a word prediction feature. A six-word prediction list with a fixed word order was used, presented vertically in the top left corner of the screen. Able-bodied subjects used mouthstick typing, while subjects with spinal cord injuries used their usual method of keyboard access, which was mouthstick typing for two of the subjects and hand splint typing for the other four.

Experimental Design. An alternating treatments design was employed, in which subject performance with and without word prediction was recorded in each of seven test sessions. The keystroke savings provided by word prediction was fixed across Sessions 1 - 4 and varied in Sessions 5, 6, and 7. Each subject was assigned a particular strategy with which to use the word prediction feature. Labels for the four subject groups are shown below:

	SCI No	SCI Yes
Strategy 1	AB1 (n=4)	SCI1 (n=3)
Strategy 2	AB2 (n=4)	SCI2 (n=3)

Training. In the first part of training, subjects were instructed in the text transcription task and use of the mouthstick, for able-bodied subjects. Subjects then practiced using the Letters-only system for six blocks of text (four sentences each). The second part of training introduced subjects to the Letters+WP system and their assigned strategy for its use. The rule for Strategy 1 was to search the list before every selection. The rule for Strategy 2 was to choose the first two letters of a word without searching the list, then search the list before each subsequent selection. For both strategies, a search was not required when the list was empty. Subjects practiced using their strategy for four blocks of text (4 sentences each), which was sufficient for each to use the strategy correctly without prompting.

Testing. Each of the seven test sessions involved four sentences of warm-up using word prediction, an eight sentence test with word prediction, then a two sentence typing test. Text blocks were drawn from published typing tests [9] and revised to provide the levels of keystroke savings shown in Figure 1.

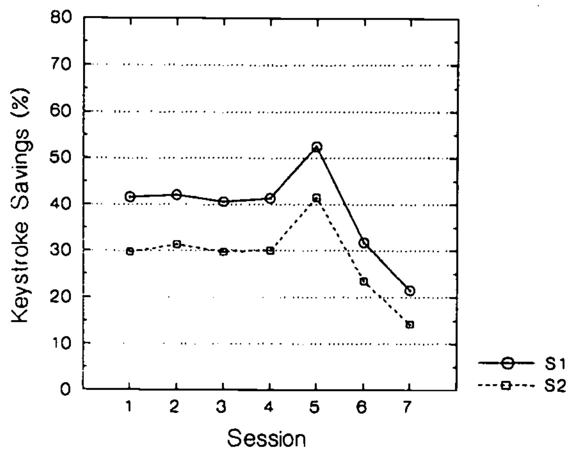

Fig. 1. Keystroke savings for strategies S1 and S2.

Sentences were presented singly on index cards. Subjects had twenty seconds to read the sentence before an audio cue signalled them to begin transcription, during which they could refer back to the card if necessary. Errors could be corrected by selecting the "Backspace" key as well as a special key for correcting word list selections.

Data Collection and Filtering. Subject behavior was recorded on videotape. Additionally, selected items were timed and stored by the software in real time. These data were filtered to remove events judged to be in any of the following three categories: text errors and error corrections; words not entered in a manner consistent with the assigned strategy; and "card reads", or times when the subject referred back to the text card during transcription.

User Performance Measures. Text generation rate and item selection rate were measured at each test session for both the Letters+WP and Letters-only systems. Text generation rate was defined as the number of characters generated during the test divided by the total time required to generate those characters. Item selection rate was defined as the number of items (i.e., keystrokes) selected during the test divided by the total time.

Statistical Analyses. Statistical differences in the dependent measures were determined using a repeated measures ANOVA technique. The between-subjects factors were strategy and presence/absence of spinal cord injury, and the within-subjects factors were system and session. Statistical significance for each ANOVA test was judged at a familywise p-value of 0.05.

Results

Filtering. The percentage of data removed from analysis averaged 16.3% of all Letters+WP selections and 7.3% of all Letters-only selections. The total amount of data filtered was independent of spinal cord injury, strategy used, or session.

Text Generation Rate. Subjects with spinal cord injuries averaged 116 characters/minute with Letters-only typing, which was significantly faster than the able-bodied subjects, who averaged 70 char/min ($p=0.005$). In contrast, subjects' text generation rates with the Letters+WP system were strikingly similar, averaging 71 char/min, with no statistical differences due to strategy or spinal cord injury.

The difference between spinal cord injured and able-bodied subjects re-emerged in examining the net change in text generation rate with Letters+WP relative to Letters-only, as shown in Figure 2 ($p < 0.0005$). For spinal cord injured subjects, word prediction had a strongly negative impact on text generation rate; on average, rate decreased by 40.7% when word prediction was used. For the able-bodied subjects, text generation rate was not significantly affected by the use of word prediction, except during Session 5, which had the highest level of keystroke savings and improved rate by 31.9%, and Session 7, which had the lowest keystroke savings and inhibited rate by 14.0%. Strategy of using Letters+WP had no effect on rate improvement for the able-bodied subjects, while spinal cord injured subjects who used Strategy 2 had a significant advantage over those who used Strategy 1 ($p=0.014$).

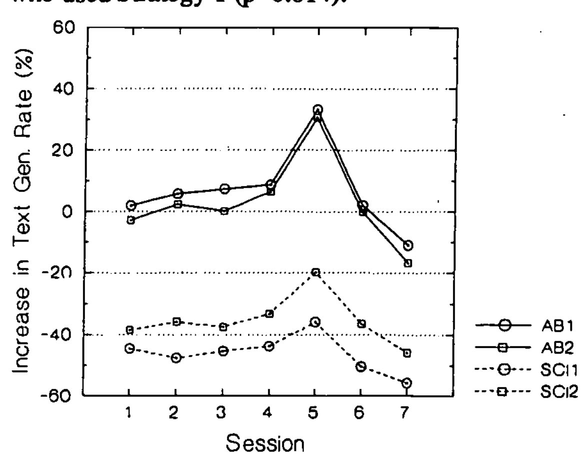

Fig. 2. Percent increase in text generation rate with Letters+WP, relative to Letters-only.

Item Selection Rate. For all subject groups, the item selection rate was significantly slower for the Letters+WP system than for Letters-only ($p < 0.0005$). Figure 3 illustrates this decrease as a relative percentage of the item selection rate with Letters-only. The effect of word prediction on item selection rate was larger for the spinal cord injured subjects ($p < 0.0005$); their item selection rate was

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61.5% slower with Letters+WP as compared to Letters-only, while for able-bodied subjects, the average decrease in item selection rate was 31.8%. The strategy with which Letters+WP was used also influenced the decrease in item selection rate ($p < 0.003$). For both able-bodied and spinal cord injured subjects, item selection rate decreased less with word prediction for those who used Strategy 2 (which involved fewer list searches).

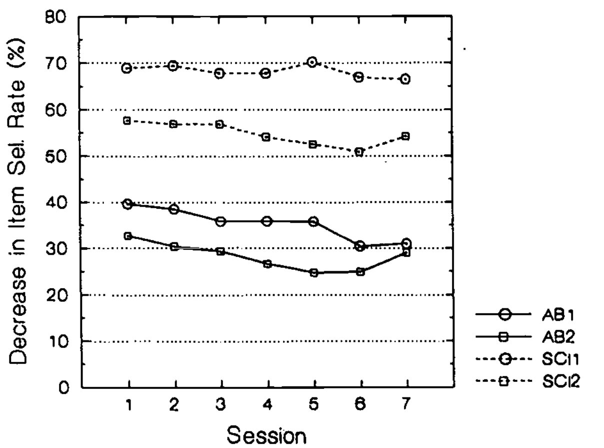

Fig. 3. Percent decrease in item selection rate with Letters+WP, relative to Letters-only.

Discussion

These results provide additional support for the hypothesis that increased cognitive and perceptual loads have a major impact on performance with word prediction. Any improvements in rate with word prediction relative to letters-only typing were much less than would be expected based on keystroke savings alone. Additionally, a statistically significant improvement was seen only for the able-bodied subjects, and only for the session that provided the highest keystroke savings. In all other sessions, able-bodied performance with word prediction was not significantly faster than without, while for spinal cord injured subjects, performance with Letters+WP was significantly worse than for Letters-only typing.

To determine the net effect of word prediction on performance, both keystroke savings and the cognitive cost of using the system must be considered. For example, use of Strategy 2 in this study provided lower keystroke savings but yielded performance at least as good as Strategy 1, because the fewer list searches required with Strategy 2 exacted a lower cognitive cost. As a second example, spinal cord injured and able-bodied subjects achieved the same keystroke savings, but the spinal cord injured subjects did much worse with word prediction than the able-bodied subjects, relative to letters-only typing. This suggests that the cost of word prediction was higher for the spinal cord injured subjects, which may be related to their greater *a priori* skill in letters-only typing.

The generalizability of these results is limited by features of the experimental conditions. Subjects were constrained in what strategy they were to use with Letters+WP, the text they were to generate, and the number of sessions in which they used the systems. Additionally, the spinal cord injured subjects represent only one sub-group of the actual user population, which includes individuals with more variable motor skills as well as those with cognitive impairments. Future work should focus on the performance of users with different abilities and levels of expertise than the subjects studied here, to either corroborate these results or reveal the conditions under which word prediction does provide a large improvement in rate.

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Pilot Study of the Effects of Visual Feedback on the Grasping Function of Prosthetic Hands

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Abstract

Upper limb amputees lack the benefit of tactile and proprioceptive feedback while using their prosthetic hands. They rely almost exclusively upon vision to determine how well objects are grasped, if slippage is occurring, or if the object is being crushed by excessive force. An understanding of how visual feedback affects grasping performance could be an important tool for the prosthesis designer.

A method of quantifying visual feedback and its effects on prosthetic grasping function is presented and evaluated. Methods-Time Measurement is used for evaluation, and a head mounted camera to record what the user can see while performing a grasping task. The data from 3 pilot tests were evaluated and suggest that the technique is suitable to aid in the understanding of the role of visual feedback related to grasping function.

Background

The human hand is an engineering marvel. It is an adaptable instrument that can apply brute force or effect fine manipulation. Simultaneously, it provides intricate tactile, proprioceptive and temperature sensory feedback. In comparison, current prosthetic hand replacements are exceptionally crude mechanisms. It would be difficult to identify whether prosthetic hand function is limited more by the mechanical or sensory systems. Modern electromechanical anthropometric hands have made advances in mechanical performance over the conventional body powered split hooks while the hook provides better visual feedback to the user.

Visual feedback is a commonly noted functional benefit of the conventional split hook over anthropometric prosthesis (*1*). The orientations of the grasping surfaces to the user's line of sight and the slim profile are potential reasons for this advantage. The importance of visual feedback for anthropometric designs is illustrated in a recent pilot survey involving 5 upper limb prosthetic centres where visual feedback was identified as an important but lacking characteristic of current child-sized myoelectric hands (*2*).

Grasp configuration of the prosthesis has been reported to influence both visual feedback (*3,4*), and grasping performance (*5*). It was also suggested that while performing grasping tasks, improved visual feedback results in a reduction of compensatory movements.

There has been considerable interest in alternative feedback mechanisms for powered prehensors in an effort to reduce visual dependency (*6,7,8,9*). Even with these additional sensory inputs, visual cues are found to be the most important.

Problem Statement

To date, there have been no published methods to evaluate or quantify the visual feedback of prosthetic hands. Likewise, there has been no suggestion as to what constitutes "good" or "bad" visibility related to prosthetic grasp. This lack of knowledge prevents a systematic optimization of prehensor configurations to enhance this characteristic.

Objective

The objective of this research was to identify how visual feedback relates to the grasping performance of a prosthetic hand. A test was proposed that attempts to determine how the visibility of specific areas of anthropometric prosthetic hands affects the time required for a user to attain a grasp. It was suggested that this can be used to quantitatively evaluate how visual feedback affects the performance of various prosthetic devices. The ultimate goal of this research is to provide additional information to aid the prosthesis designer to produce a more functional prehensor.

Research Questions

1- Can the effects of visual feedback be quantified?
2- Does this method quantify visual feedback?
3- Can correlations be found between visual feedback and the grasping performance of a prosthetic hand?

Test Method

To identify a correlation between visible areas of the hand and grasping performance of a prosthesis, three areas were addressed. First, a task was developed that required the user to demonstrate diversity of the independent variable, visual feedback. Second, a method of evaluating performance was proposed. Finally, a method of identifying what visual feedback the user has while performing the task was implemented.

Grasping task

The grasping task was developed to encourage a variety of grasp approaches thereby changing the visual feedback to the subject.

The task involved reaching for and grasping a small cylinder then moving it to another defined position and releasing it. Nine of these cylinders are arranged in a 3 by 3 matrix

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scaled to the subject's dimensions made up a single trial. Each cylinder was aligned in one of three orientations, vertical (1), horizontal facing away (2), or across (3) the subject. The orientation of the cylinders was in a Latin square such that each orientation occurred only once in any row or column to facilitate data analysis. Each subsequent trial randomly altered the orientation pattern of the matrix to reduce learning effects.

The cylinder dimensions (12 mm dia. x 65 mm) required a precisely aligned tip or pulp type grasp with the prosthesis so that each orientation required a different grasping posture that could be effected by adjustments in wrist orientation or compensatory motions of the shoulder and torso. The cylinders were balanced on 4 closely spaced pins, 12 mm above the table surface to increase the grasp alignment accuracy required. This prevented the subject from pushing the cylinder into a preferred orientation before picking it up.

Twelve trials were performed per test so that each orientation occurred in each position 4 times for a total of 108 grasps.

Evaluation of performance

Gilad identified the ability to align and attain a grasp using a prosthesis to be the most affected function when compared to the natural hand using Methods-Time Measurement (MTM) (*10*). MTM is a standard method of motion analysis based on a breakdown of activities required to perform a given task into its component parts (*11*). The motion elements required in this experiment were *reach*, *grasp*, *move*, *position*, and *release*. By analyzing video records of the experiment frame by frame and employing MTM standards to define the beginning and end of each activity, the time required to perform the given task can be broken into its component parts. Previous studies have shown that the time required to perform the element *grasp* is greatly affected by the prehensor configuration (*5*).

The subject was positioned under a mirror slanted 45 degrees below vertical allowing a single video camera to record both top and front views. Both the backdrop and table top were gridded to aid in observing movement.

Identification of Visibility

A miniature CCD camera was mounted on the subject's head, close to the line of vision. Video tape recorded what the subject could see when performing the task. The primary grasping components of the prosthesis consisted of the thumb, index and middle fingers. For recording purposes, these components were further divided into palmar, lateral, dorsal and medial surfaces of each phalangeal segment for a total of 32 segments. These areas were marked with a high contrast border that was discernible by the head mounted camera. The visible areas at the start of the *grasp* motion element were identified from the video tape.

Results

Subject information

The subject for the pilot test was a 29-year-old female with a traumatic trans-radial amputation of the dominant arm. She was fitted with a myoelectrically controlled prosthetic hand 2 years prior to the test. She typically uses an anthropometric prostheses except during her employment where a body powered split-hook is used.

Test procedures

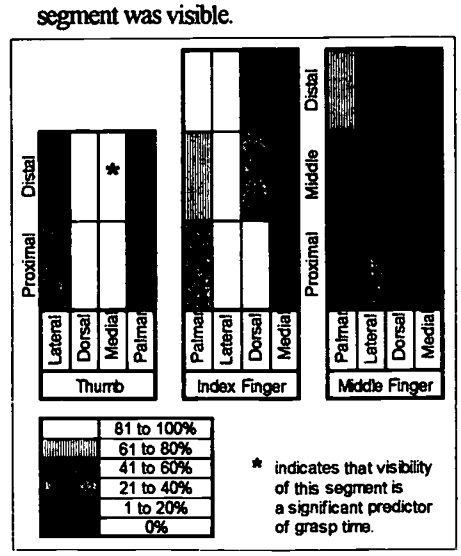
The initial test was performed using an Otto Bock 7-1/4 inch hand. Following this test, the subject was supplied with an identical fitting new Centri Ultralight myoelectric hand. She was instructed to use the new hand as much as possible prior to the next set of tests one week later. The second test was performed with the Otto Bock 7-1/4 inch hand followed by the third test with the Centri hand. In each test the subject was permitted several unrecorded practice runs to become accustomed to the task with the specified prehensor. The data was processed and grasping times were normalized so that the data could be compared between tests.

It was found that a single test of 108 grasps requires approximately 1 hour of subject testing followed by 10 hours of manual processing to obtain the raw data.

Task Evaluation

The task itself was evaluated to ensure it encouraged variability in the grasps. Statistically significant variations in grasping times were observed depending upon: the cylinder orientation; which column it was grasped from; and the combination of orientation and column. The greatest difference was predicted by the cylinder orientation. No significant variations were indicated by row or any other combinations of row, column or orientation.

Figure 1, Percentage of total grasps for which each finger segment was visible.



The task also encouraged a degree of variability in which segments were or were not visible for a given grasp. Figure

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1 shows the percentage of grasps in which the individual segments were visible with data averaged from all tests. Nine segments were visible for more than 80% of the grasps while only two (distal and medial lateral surfaces of the index finger) were always visible. Fifteen other areas were visible for less than 20% of the grasps. It was interesting to note that the subject made considerable efforts to maintain visibility of certain segments of the hand even if large compensatory motions were required.

Correlations between visibility and grasping time

A multiple regression was performed to attempt to predict the grasping time given the segments of the hands that are visible. The predictive formula would be in a form similar to:

$$\text{Grasp Time} = \text{Int} + \quad [C(n) \times V(n)]$$

where V(n) is the visibility of segment n. V(n)'s value is 1 if it is visible, and 0 if not. The regression model identifies coefficients C(n) and the intercept (Int) that produce significant predictions.

With the small amount of data considered, 8 segments were found to be significant predictors of the grasping time. These segments are marked on figure 1. Using this data, up to 32% of the grasping time uncertainty could be eliminated. While not enabling accurate prediction of grasp time, the coefficients indicated whether grasp time got faster or slower and by how much when the respective segment was visible.

An example with orientation 1, factor(3) was found to be -4.8. This suggests that according to the statistical model used, the predicted grasping time would be reduced by 4.8 time units when segment(3) is visible. Conversely, factor(20) was +19.0, so that when segment(20) was visible, it could be predicted that the grasping time would be higher by 19 time units.

Discussion

The analysis shows that the grasping task provides an adequate variability in both grasping time and visibility. Since there was no significant variation in grasping times based on the row, this variable can be eliminated from the analysis. There are no substantial problems regarding mechanics of collecting and processing this data.

This research will continue to collect and analyze data from a number of subjects to identify how the visibility of these segments affects the grasping performance of the prosthesis. This information will also allow comparison between different prostheses. Armed with this information it may be possible to improve the performance of prosthetic hands by optimizing the visual feedback to the user.

Acknowledgments

The Natural Sciences and Engineering Research Council and the Powered Upper Extremity Prosthetics Program at HMRC are thanked for their support.

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EXPERIMENTAL DETERMINATION OF STRESS DISTRIBUTION DUE TO WHEELCHAIR DYNAMIC LOADS FOR USE WITH FINITE ELEMENTS.

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Abstract

Wheelchair users can benefit from improved cost/reliability and performance of wheelchairs. The finite element method provides means for accomplishing this increase in performance, but is only as valid as the input loading conditions. A method is presented to transform experimentally determined acceleration data into a model for the stress distribution acting on a wheelchair due to dynamic loads. The dynamic load considered is the ISO/RESNA Curb-Drop test. The results show a highly asymmetric stress distribution which is consistent with an uneven impact with the floor. This result confirms the necessity for using experimentally determined data. Furthermore, the results can be used to suggest improvements to the Curb-Drop test itself.

Introduction

The long term survivability of a wheelchair has a twofold importance. First, the reliability of a wheelchair impacts the security of the wheelchair user. Second, the longevity of a wheelchair directly affects it's operational costs to the user and/or insurer. Several authors have made attempts at characterizing the dynamic loads which wheelchairs are subjected to by wheelchair users. Presently, these experiments have focused on the RESNA/ISO standardized tests. Three of the more prominent methods are strain gage instrumentation (1,2), accelerometry (3,4), and computer simulation (5).

The next step after the characterization of dynamic loads is to use the experimentally determined dynamic loads to design an improved wheelchair. The finite element method is beginning to be used for the design of wheelchair frames (6). The finite element method can only represent real loading conditions to the extent that the input loading conditions represent real loading conditions. This paper deals with the problem of transforming experimental accelerometer data into a model of the normal stresses acting on the loading surfaces of the wheelchair. These stresses can then be directly entered into a finite element program.

Methods

Experiment
Two ultralight wheelchairs (A and B) were tested according to ISO/RESNA Curb-Drop protocol. Each of these wheelchairs were dropped six times. The ISO/RESNA test dummy (TD) was instrumented with twelve accelerometers. Figure 1 shows the layout of the accelerometers for the TD lap segment. The accelerometer layout for the back segment is similar. For three drops, the back segment of the TD was instrumented and for three drops, the lap segment of the TD was instrumented. A complete description of the accelerometer protocol is given in (4).

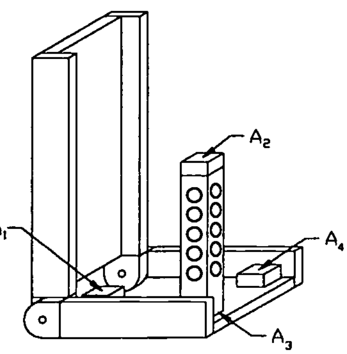

Figure 1: Accelerometer block locations on test dummy lap segment. Each accelerometer block contains three orthonormal accelerometers. One block is elevated by an extended.

The back and lap TD segment data was individually filtered with an analog Butterworth filter at the time of collection and subsequently filtered with a sixth order zero-phase Butterworth filter with a corner frequency was 50 Hz. The data was signal averaged to obtain one characteristic set of data for each wheelchair.

Theory
Equation (4) in VanSickle and Cooper (4) is presented as Eq. (1) here. The matrix in Eq. (1) is a linear transformation between an arbitrary position (**R**) and the acceleration difference ($\mathbf{A_{pq}}$) between that position and the origin. The terms of the matrix in Eq. (1) are determined by the method presented in (4).

$$\vec{A}_{pq} = \begin{bmatrix} -(\omega_y^2+\omega_z^2) & \omega_y\omega_x-\alpha_z & \omega_z\omega_x+\alpha_y \\ \omega_x\omega_y+\alpha_z & -(\omega_x^2+\omega_z^2) & \omega_z\omega_y-\alpha_x \\ \omega_x\omega_z-\alpha_y & \omega_y\omega_z+\alpha_x & -(\omega_x^2+\omega_y^2) \end{bmatrix} \begin{bmatrix} R_x \\ R_y \\ R_z \end{bmatrix} \quad (1)$$

Each of the TD segments are assumed to be rigid bodies. The inertial force and moment acting on the center of mass (CM) of each TD segment combined with the external force and moment exerted by the opposing dummy segment completely determine the loading of the segment. Figure 2 is a diagram of the two dummy segments and illustrates the interacting force and moment between them.

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It is assumed that the shear stress along the TD surface is small compared to normal stress.

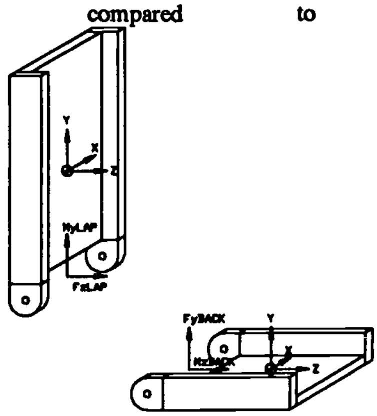

Figure 2: Test dummy coordinate system and force-moment interaction between test dummy segments.

Equation (1) is used to determine the acceleration at the CM of each TD segment. Newton's 2nd law is directly applied to find the inertial force acting on each segment. The inertial moment acting about the CM is found using Equation (2) (7). The matrix **I** is the inertia matrix. For the case where the coordinate system is aligned with the principle axes of the dummy segments, the off-diagonal terms of **I** vanish. Equation (2) reduces to Equations (3). The angular acceleration terms and angular velocity cross terms can be determined by decomposing the matrix in (1) into a symmetric plus an antisymmetric matrix.

$$\bar{M} = [I]\bar{\alpha} + \bar{\omega} \times ([I]\bar{\omega}) \qquad (2)$$

$$\begin{aligned} M_x &= I_{xx}\alpha_x + (I_{zz} - I_{yy})\omega_y\omega_z \\ M_y &= I_{yy}\alpha_y + (I_{xx} - I_{zz})\omega_x\omega_z \\ M_z &= I_{zz}\alpha_z + (I_{yy} - I_{xx})\omega_x\omega_y \end{aligned} \qquad (3)$$

A linear equation is used to model the stress along the loading surfaces of the TD segments. Equation (4) is the model for the TD lap segment. The coefficients of (4) are determined by equating the moments derived from the data and those produced by the linear model. The loading surfaces of the TD vary in only two dimensions. Therefore, one parameter in the model is arbitrary. For the lap σ_{yy} is arbitrary. It is convenient to set σ_{yy} to zero.

$$\sigma_y(x,y,z) = \sigma_{yx}x + \sigma_{yy}y + \sigma_{yz}z + \sigma_{yAVE}. \qquad (4)$$

At each of the finite element nodes, the stress predicted by the linear model is converted into a force by multiplication with the area associated with that node.

Results

Figure 3 shows the distribution of acceleration along the loading surfaces of the TD for wheelchair A. Due to rotations, the acceleration distribution along the back of the wheelchair is curved. This effect is more noticeable in the view presented in Figure 4. Only the accelerations in the x direction are shown. The accelerations at the upper left and lower right of the view in Figure 4 are opposite in magnitude. The zero acceleration line along the back is the axis of rotation.

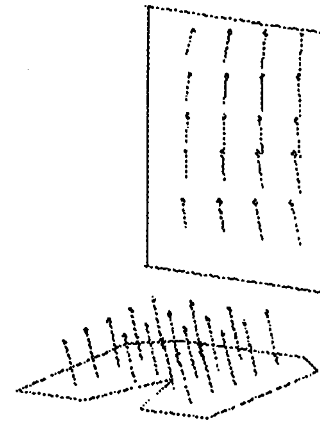

Figure 3: Accelerations at locations along the loading surfaces of the TD for wheelchair A.

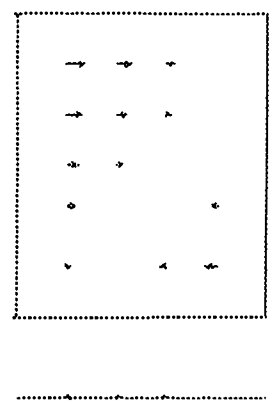

Figure 4: Accelerations in the medial-lateral direction only for the loading surfaces of the TD in wheelchair A.

Figure 5 illustrates the time sequence of both the average normal stress and the normal stress gradients. The maximum average normal stress is 2.02×10^3 N/m^2. The maximum normal stress gradient is 186.5×10^3 N/m^2/m. Both of these maxima occur at 111 ms after contact with the floor.

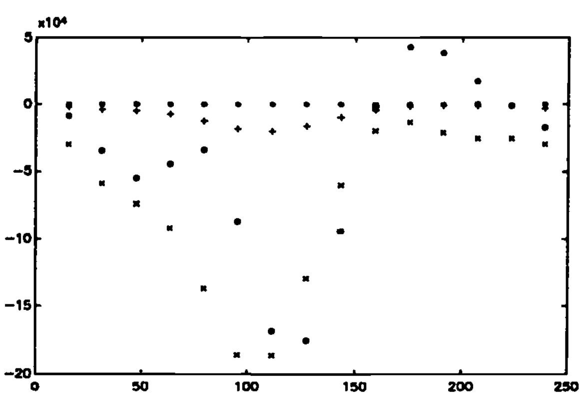

Figure 5: Test dummy lap segment average stress (N/m^2) and stress gradients (N/m^2/m) for wheelchair A. σ_{yAVE} = "+"; σ_{yx} = "*"; σ_{yy} = "o"; σ_{yz} = "x".

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Figure 6 illustrates the peak stress acting on wheelchair A. The arrows represent the relative magnitude of force (stress x nodal area) corresponding to each finite element node. The peak stress is 68.1×10^3 N/m^2 at 111 ms after contact with the floor. An important features of Figure 3 is the sharp gradient of the force distribution. The stress distribution for wheelchair B is a mirror image of the stress distribution for wheelchair A.

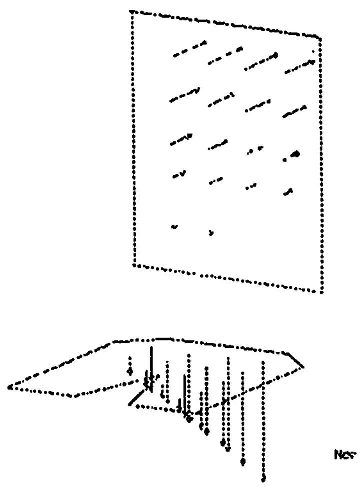

Figure 6: Peak dynamic stress acting on wheelchair A.

Discussion and Conclusion

The importance of using experimental data is shown in the results. Most wheelchairs are presently designed with an assumed static load which is a multiple of the expected users weight. This multiple is often about 3. The multiple is supposed to account for any dynamic loads which might occur during use. The loading scheme shown in Figure 5 is quite different from a static load. From the shape of the stress distribution it is clear that the left side of the wheelchair contacted the ground before the right side. This occurred even after the wheelchair was deliberately placed to drop evenly as outlined in the ISO/RESNA standards.

Due to the sensitivity of the Curb-Drop test to initial setup, some doubt about the tests validity must be :xpressed. Some wheelchairs may have most of the dynamic loads focused on one side during the test which could artificially shorten the number of cycles until failure. A potential solution to this problem would be to force a small deviation to the left or right which would produce intentional eccentric loading. The deviation could be alternated to create a reproducible and more realistic test regime. A future study may show that real curbs and others obstacles produce asymmetric loading.

It is doubtful that the finite element method can be implemented without the use of experimentally determined loads and still yield valid conclusions about the long term reliability of a proposed wheelchair design. Future studies will be needed to produce a bank of data for several classes of wheelchairs operated under many loading conditions. This data bank can then be used by manufacturers to design more reliable and cost effective wheelchairs.

Acknowledgments

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THE APPLICABILITY OF NEURAL NETWORKS IN AN AUTONOMOUS MODE SELECTION SYSTEM

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ABSTRACT

Human-machine systems with adaptive shared control attempt to maximize the performance of both the machine and its human operator by allowing the machine to adapt to changing environmental and functional requirements, much as the human does. The NavChair assistive navigation system [2] is an example of one such system where control of the wheelchair is shared by the user and autonomous navigation methods. One of the needs of such a system is a method of determining the appropriate mode of operation at any given time. To do this, the system must be able to identify objects around the wheelchair. The ability of neural networks to perform this task was examined.

BACKGROUND

A common goal of human-machine systems is to make maximal use of the abilities of both the machine and the user and therebye perform tasks that neither could perform independently. One of the most important abilities that the human brings to such a system is adaptability to changes in the environment and functional requirements. If machines also demonstrated adaptive ability towards the user and/or environment, then the performance of the system could be improved.

A desirable method of adaptation is one that is based on the user's control inputs and requires no additional user interaction. This type of adaptive control behavior would be applicable in a variety of domains, such as vehicle control. Autonomous adaptation can provide assistance and reduce the demands on the operator, especially at critical points in time when aid is most needed but the operator has the fewest resources to devote to interacting with the system.

The NavChair assistive navigation system is one example of an adaptive shared control system. The objective of the NavChair project is to provide mobility to individuals currently unable to operate a powered wheelchair. By assisting the user in making vehicle control decisions regarding avoiding obstacles, approaching objects safely, and maintaining a straight path it is hoped that the motor, cognitive, and perceptual effort required to operate a wheelchair can be reduced.

The NavChair prototype is based on a standard Everest & Jennings Lancer powered wheelchair. The components of the NavChair system are attached to the Lancer and receive power from the chair's batteries. The NavChair system consists of three units: (1) an IBM-compatible computer which receives voltages transmitted by the joystick and outputs control signals for the wheels, (2) an array of 12 Polaroid ultrasonic transducers mounted on the front of a standard wheelchair lap tray, and (3) an interface module which provides the necessary interface circuits for the system [2].

A need has arisen during the design of the NavChair system which requires the controller to be able to adapt itself to different situations. Control parameters which allow for effective obstacle avoidance in cluttered environments preclude other behaviors, such as close approach to objects, door passage or wall-following. Several different driving modes which allow for the variety of desired behaviors have been developed in response to this need. However, manual switching between modes requires additional interaction from an operator who may already have marginal abilities for operating a wheelchair.

What is needed is a method by which the system can use observations of user behavior and the surrounding environment to autonomously make these mode selections. The key task in designing such a system is the implementation of a "mode manager", which would (ideally) be able to infer the user's goals based on the user's input, the wheelchair's surroundings, the status of the wheelchair, and past inferred goals.

The research presented in this paper was undertaken to fulfill a part of this need by providing the capability of classifying objects around the wheelchair from the sonar sensor readings the chair uses to navigate. This task can be neatly placed in the category of pattern recognition, the pattern in this case being sonar sensor readings. This led to the choice of neural networks because they have been shown to be highly successful at pattern recognition tasks. While this research was undertaken to address a specific need of the NavChair system, it is believed that it can be applied to a wide variety of shared control systems, both within the rehabilitation field and in other unrelated fields.

RESEARCH QUESTIONS

In order to evaluate whether or not neural networks were appropriate for the NavChair system, several key questions needed to be answered:

1) Could a neural network identify surrounding objects accurately enough that it could be integrated into the NavChair system? The system involves a human operator and valuable equipment so safety is a primary concern and accuracy is very important. The criterion chosen for acceptable accuracy was correctly classifying 90 percent of the individual readings. This is expected to yield accuracy of almost 100 percent in practice because many sonar readings are taken each second and the envisioned system within which the networks would be embedded will maintain a history of previous decisions. Thus any individual decision returned by the network is averaged over several previous ones, making each individual decisions less important.

2) How quickly could a neural network provide acceptably accurate answers? The speed of the chair is ultimately bounded by how quickly the NavChair system performs its computations. The network must return an answer quickly to allow the chair to travel at a reasonable speed.

3) How much system memory would a neural network require? Additional hardware requirements, such as computer memory, translates into additional cost for the system.

METHOD

In order to examine the feasibility of integrating neural networks into the NavChair system, several networks which detect the presence of walls on the left side of the wheelchair were designed and tested. The task of identifying walls was chosen as representative of the general problem of designing neural networks to recognize objects important to the NavChair. In addition, identifying walls will be essential to implementing a wall-following mode, so it is also a task of interest to the larger NavChair research project. The choice of the left side was arbitrary and the networks could just as easily have been designed to detect walls to the right or front of the chair. The neural networks focused on only one side of the chair to simplify data collection for training the networks.

The neural networks used in this experiment were two-layer feed-forward backpropogation networks. The term feed-forward refers to networks that are organized into layers, the units in a single layer only receive input from units in the layer immediately beneath and send their output only to those in the layer directly above, hence the term feed-forward. Backpropogation refers to the method by which the network was trained. In order for a network to be useful, each unit's threshold and the weights of the interconnections between units must be determined. The goal of training is to set the weights and thresholds such that the network produces the correct response to each input pattern.

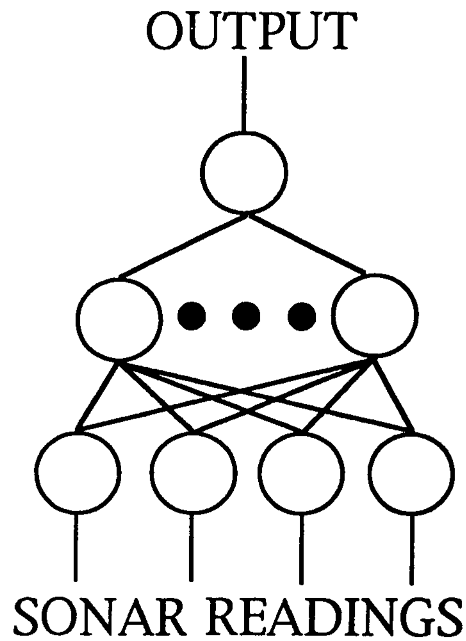

Figure 1: Diagram of Multi-Layer Networks

The program that implemented, trained, and tested the networks was compiled using the Borland Turbo C++ Compiler on an IBM PC-compatible computer. The algorithm for the code was derived from Hertz, Anders, and Palmer [1].

For each neural network, the input layer consisted of four units, each one receiving the output of one of the four sonar sensors on the left side of the wheelchair. Each output layer contained only one unit, which was to output the value one when a wall was detected and zero when a wall was not detected. The size of the hidden layer was varied in order to estimate the number of units that led to best performance. A diagram of the general network architecture used is displayed in Figure 1.

A total of 1535 readings from the sensors on the left side of the chair were taken. Of these, 1023 were used as training inputs and the remainder were used to test the neural networks. The training file was presented to each network 1000 times, after which the network's performance on the test inputs was measured. This process of training and testing was repeated for each network until no further gains in accuracy were observed.

In order to evaluate the performance of the networks an error threshold of 0.2 was used. This meant that the network had to produce a value less than 0.2 for inputs that corresponded to no wall being present (zero being the desired output) or an output of at least 0.8 for inputs corresponding to a wall being detected (one being desired) in order for its output to be considered correct.

RESULTS

Table 1 shows the results achieved by the neural networks tested during this research. As shown in the table, one of the networks performed the task at above 90 percent accuracy and two others reached levels of over 85 percent. These results demonstrate that it is indeed possible for multi-layer networks to perform wall identification when trained by the backpropogation algorithm.

Although it was not a primary concern of this research, testing also revealed that using backpropogation to train a network to perform this task takes very little time. Each of the networks was trained in under two hours, which can be attributed mostly to the relatively small size of the networks used. While this may not seem important, this represents a significant reduction from the time it would take to generate the corresponding computer code to perform the same task.

DISCUSSION

As with any research, one must carefully consider what conclusions can be drawn from the above data. Foremost, the level of accuracy achieved by the networks is very promising. It is more than adequate for the purposes of the NavChair system and shows that neural networks are definitely a viable alternative for use in the "mode manager."

The fact that the most successful network did not require many hidden layer units adds to the attractiveness of neural networks. A feed-forward network with 4 input nodes, 15 hidden layer nodes, and 1 output node requires 75 additions and 75 multiplications to evaluate, which would not take much time to compute. This is crucial because the speed with which the NavChair can move is limited by the speed with which it can complete its computations.

In addition, it is likely that once a network has been trained to perform a function such as identifying walls, it would be implemented in the chair as a "hard-wired" formula, thus shedding much of the explicit neural network architecture (such as the arrays of interconnect weights between nodes). This would decrease both the amount of time spent computing the response to an input pattern by reducing the amount of time retrieving values from memory, and also lessen the amount of system memory that the network required.

The results are encouraging and suggest that neural networks may be appropriate for use in many other systems with needs similar to the NavChair system. Neural networks can provide accurate recognition without introducing significant time or memory overhead, which makes them attractive alternatives for many adaptive control systems.

Number of Units in Hidden Layer	Number of Correct Answers	Number of Wrong Answers	Percent Correct
1	256	256	50.00%
5	283	229	55.27%
9	378	134	73.83%
10	456	56	89.06%
15	480	32	93.75%
20	368	144	71.88%
25	438	74	85.55%
30	419	93	81.84%
70	375	137	73.24%

Table 1: Results of Testing for Multi-Layer Networks Trained With Backpropagation Algorithm

While the above can be concluded, there are many issues still left open. It is unknown whether the data returned by the sonar sensors used by the NavChair will be sufficient for a neural network to accurately identify other objects. Walls provide relatively consistent interaction with the sonar sensors, but doorways are not so kind. It may prove necessary to use different, or additional, sensors to accurately identify other features such as open doors.

The size of the network also has not been conclusively determined. Because each network is initialized randomly, a great deal of testing would be required to determine how many hidden layer units provide the greatest accuracy. However, accuracy is not the only factor affecting the size of the network; how fast the network returns an answer is also crucial, which could prompt the sacrifice of some accuracy for reduced processing time.

For this reason, alternative neural network architectures and training methods need to be examined. There are several enhancements to the backpropogation method that might produce smaller, more accurate networks. In addition, there are many different architectures and training methods, and while many of these were examined during the course of this research there are certainly many more that could be evaluated.

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DESIGN CRITERIA FOR OBSTACLE AVOIDANCE IN A SHARED-CONTROL SYSTEM

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Abstract

The NavChair assistive navigation system was originally conceived as an application of mobile robot obstacle avoidance to a power wheelchair. In this system, the user shares wheelchair control with obstacle avoidance and other navigation components. The philosophy of shared control has important implications for the design of these components. This paper discusses the development of a new obstacle avoidance routine for the NavChair guided by design criteria for shared control systems.

Introduction

The NavChair assistive navigation system (1) is being developed to improve the mobility and safety of people who have sensory, perceptual or motor impairments that limit their ability to operate a power wheelchair. The NavChair control systems is designed to avoid obstacles, travel safely through doors and provide other forms of navigation assistance under the direction of the wheelchair user.

The NavChair is a human-machine system in which the user and machine must share control (2). The user is responsible for high-level control of the system, such as route-planning and some navigation actions, while the machine overrides unsafe maneuvers through autonomous obstacle avoidance and can provide addition assistance such as automatic wall following. The user indicates the desired direction and speed of travel with a standard joystick. Various navigation routines modify this command, if necessary, to provide safety and/or improved navigation through a combination of slowing the chair and changing its direction of travel. The system attempts to change the user's command as little as possible while insuring safe, effective travel.

In addition to jointly determining the motor command, the user and the NavChair must be able to cooperatively adapt to changes in environmental or function conditions. Human users adapt rapidly and naturally but machines must be programmed to adapt in response to changes in measurable variables. This makes human-machine co-adaptation difficult, because it requires that the machine monitor user adaptation in real time.

Our attempts to understand cooperative adaptation in the NavChair have lead to design criteria for control system components. The application of these criteria has revealed faults in the original robotic obstacle avoidance method and guided the development of a new obstacle avoidance technique. The following section outlines some of our previous work related to shared control and the development of design criteria. We then apply these criteria to the redesign of the obstacle avoidance component of our system and briefly describe the operation of the new algorithm we have developed.

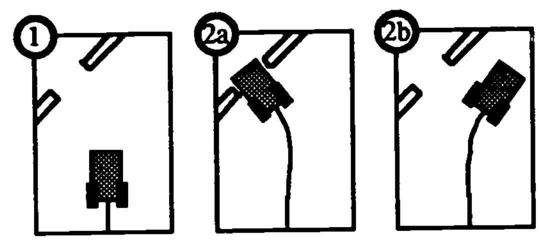

Figure 1: Mode Selection: Frame (1) shows the NavChair approaching a doorway. One of two outcomes is possible: either (2a) the NavChair performs door-passage behavior, or (2b) the NavChair performs an avoidance maneuver. These two behaviors correspond to two modes of operation, door-passage and obstacle avoidance, that cannot be performed simultaneously.

Cooperative Adaptation

To make this discussion of cooperative adaptation concrete, we will discuss the scenario depicted in figure 1 in which the NavChair must select between two mutually exclusive modes of operation on the basis of measurable variables. In this case, environmental variables are not sufficient to determine mode selection because the presence of a door doesn't always imply that the user wishes to travel through it. The decision to change modes must also be based upon the behavior of the user.

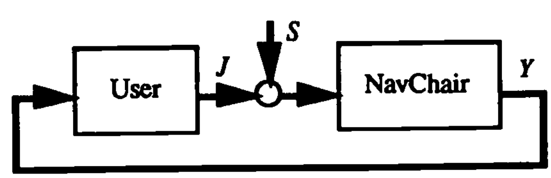

Figure 2: Stimulus Response Modeling: Observations of responses to an applied stimulus, S, are used to model the behavior of the user. The stimulus perturbs the motion of the wheelchair, Y, which evokes a response in the joystick command from the user, J.

We have developed a new method of automatic mode selection in response to changes in user behavior (3). This method, called "Stimulus Response Modeling," (patent pending) allows the NavChair to quantitatively monitor changes in user behavior and to adapt to these changes in real time (figure 2). We have implemented stimulus response modeling to help the NavChair perform automatic mode selection in the scenario described above. Essentially, the wheelchair begins with the default hypothesis that the user wishes to continue in obstacle avoidance mode and turns slightly to the right to avoid a collision with the wall. If the user responds by attempting to correct this path deviation *in a way that is coherent and consistent with past door-passage behavior*, then the NavChair automatically selects door-passage mode and proceeds through the door. In this way, the machine adapts to changes in user behavior.

Methods

Design Criteria

The following design criteria, which are derived from the philosophy of adaptive shared control, guided the design of the NavChair's control system:

1) The system should be able to perform the entire range of desired behavior and to control adaptation of the machine.
2) The system must be able to adapt smoothly. For example, mode transitions must be stable and intuitive for the user.
3) The degree of autonomy of control system components should be variable and independently controllable.

The use of stimulus-response modeling imposes additional constraints:

4) The system must be able to measure disturbances in control loops that involve the user. If no external disturbances are present in the system, this implies that the system must be able to apply disturbances that do not interfere with system performance.
5) The user must have a feeling of control in each control loop. For example, in the NavChair, the user must feel that small changes in the joystick command (steer and forward speed) result in corresponding changes in wheelchair motion.

Redesigning the Obstacle Avoidance Algorithm

The robotic obstacle avoidance method that was originally ported to the NavChair system was developed for use in specialized, fully autonomous systems. As the result, this algorithm, the Vector Field Histogram (VFH) method (4), is not compatible with three of the criteria listed above: 1) It does not provide effective door passage capabilities; 2) The degree of autonomy in the system is fixed (at full autonomy); and 3) Substantial changes in joystick position often have no effect on wheelchair motion. Our original attempts to port the VFH method for use in the NavChair have been described elsewhere (5). However, the application of the above criteria represents a fundamental change in control philosophy and has resulted in further changes that improve the performance of the NavChair system.

The operation of the original and modified VFH methods are outlined in figures 3 and 4. The original VFH method is fully autonomous in the sense that the system is designed to select the obstacle-free direction closest to the target direction specified by the user. The user can often move the joystick without producing *any* change in the behavior of the wheelchair. Our new method trades obstacle avoidance against the goals of the user, providing greater and more variable control to the user. We call the new method "Minimum VFH" (MVFH).

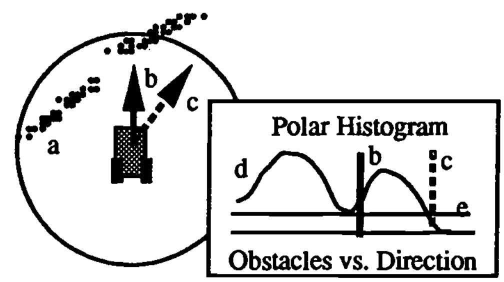

Figure 3: VFH Obstacle Avoidance: In the scenario from figure 1, sensor readings are used to update a map of obstacles in the form of a *certainty grid (a)*. The certainty grid is used to calculate a *polar histogram (d)* in which high values represent close and/or large obstacles. The *target direction* specified by the user (solid arrow, b) is modified to a *free direction* (dotted arrow, c). VFH finds the direction closest to the target direction that is below a *safety threshold (e)*.

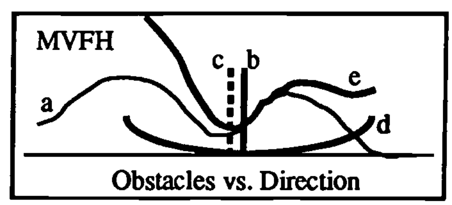

Figure 4: MVFH Obstacle Avoidance: Both VFH and MVFH use the polar histogram (a) to calculate the direction of travel. MVFH minimizes the sum (e) of the polar histogram and a weight function (d) of the distance to the target direction (b) to find a satisfactory trade-off (c). Currently this function is a parabola that allows obstacle avoidance to make small command modifications relatively easily while making large changes more difficult. In this case, MVFH centers the NavChair in the doorway, represented by the "valley" in the histogram.

MVFH provides variable component autonomy in the following sense: 1) When the target-direction weight function is a very steep parabola compared to the obstacle-density histogram, obstacle avoidance will have almost no effect on the direction of travel; 2) When the weight function is flat, the wheelchair will be effectively autonomous. Because the shape of the target weight function can be changed in real time, the autonomy of the system can be adapted to meet the instantaneous needs of the user.

Design Criteria for Shared-control Systems

MVFH does not guarantee that the wheelchair will always move in an obstacle-free direction. For these cases we have added a collision-prevention routine that slows the chair by an amount proportional to the square root of the distance to the nearest obstacle in the direction of motion. This routine smoothly decelerates the wheelchair to a stop a specified distance from obstacles. Therefore, with high autonomy, the wheelchair goes around obstacles with little decrease in speed, while low autonomy allows the user to drive the wheelchair close to obstacles and through doors. Therefore, NavChair control modes can be changed by adjusting the autonomy of the obstacle avoidance. For example, the transition from obstacle avoidance to door passage is effected by simply lowering the autonomy of obstacle avoidance to allow the user to select a path towards the door.

Results

We have found that the Minimum VFH method provides safe, effective door-passage for the NavChair. Figure 5 compares experimental results of door-passage success for the original and Minimum VFH methods. Ten trials were made at door widths from 0.7 to 1.2 meters. The ratio of successful to attempted passages was recorded for each width. Success was defined as passage without the need for user intervention due to perceived blockage. MVFH is more successful at door passage than VFH because it allows the NavChair to move closer to obstacles (the doorposts) and because it naturally tends to center the chair as it approaches the doorway. The original method merely avoids each of the doorposts.

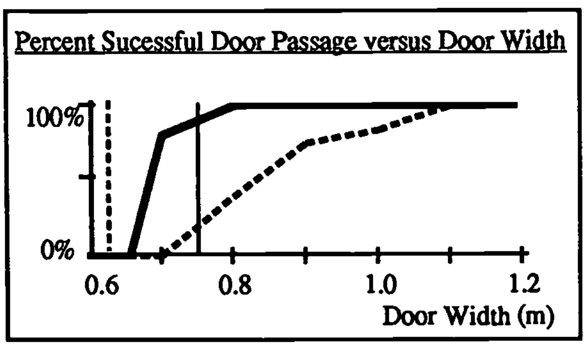

Figure 5: Door Passage Test Results: Percentage of successful door passage versus door width for VFH (dashes) and MVFH (solid). Two vertical marks provide scale: 1) dashed: the NavChair is 0.63 m wide; and 2) solid: standard doors are 0.76 m wide.

Discussion

The conformity of the MVFH method with the design criteria discussed above allows the advantages of the VFH method to be extended to a shared-control system: 1) Safe and effective door passage is possible with MVFH; 2) The level of autonomy of the obstacle avoidance is completely variable and controllable; and 3) Changes in joystick position always result in changes in wheelchair motion.

The design criteria presented above were developed in the context of the NavChair system. However, we hope that this discussion will benefit other researchers who are experiencing similar difficulties in other applications of rehabilitation engineering. In addition, this research has implications for the design of a broad variety of human-machine systems. For example, an ability to design systems capable of seamless human-machine cooperative adaptation would allow automobiles to automatically select "sport" and "economy" modes for better mileage and acceleration than non-adaptive designs.

Many rehabilitation technologies are developed as autonomous components. This research suggests that the design of human-machine control system components is substantially different than for autonomous systems. An awareness of the differences in design philosophy between autonomous and shared-control systems is necessary for the development of the best possible rehabilitation technologies and to facilitate the integration of autonomous components into effective human-machine systems.

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Acknowledgments

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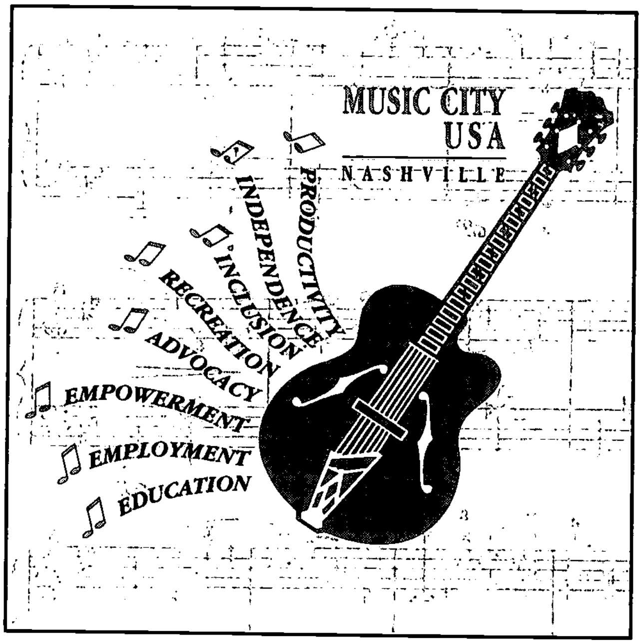

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