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ABSTRACT

These proceedings of the annual RESNA (Association for the Advancement of Rehabilitation Technology) conference include more than 200 presentations on all facets of assistive technology, including concurrent sessions, scientific platform sessions, interactive poster presentations, computer demonstrations, and the research symposia. The scientific papers included in the book address recent scientific research, practical designs, and case studies. Scientific content is grouped into the following eight categories: (1) technology for special populations, which includes: "Evaluating the Response of Children with Autism to a Robot" (Iain Werry and others) and "An Interactive Maze Game Device for Pre-Handwriting Exercises" (Jeremy M. Bowman); (2) augmentative and alternative communications (AAC), which includes "A Communication 'Tools' Model for AAC Intervention with Early Communicators" (Cynthia J. Cress); (3) computer access and use; (4) environmental accommodations ; (5) functional control and assistance; (6) service delivery and public policy; (7) research and functional outcomes, which includes "Communication Intervention Program for Deaf Adolescents" (Diane J. Grillo); and (8) seating and mobility, which includes "Quantification of Forces Associated with Episodic Full Body Extensor Spasticity in Children" (Dalthea Brown and others) and "Motorized Swing for Child up to Fifty Pounds" (Amy Congdon and Jessica Foley). The book includes papers from the student design competition and the student scientific paper competition. (Papers include references.) (CR)

# RESNA 2001 Annual Conference Proceedings

RESNA 2001

The AT Odyssey Continues

RENO

June 22 - 26, 2001

Reno, Nevada

John Ascuaga's Nugget Hotel

# PROCEEDINGS
# of the
# RESNA 2001
# Annual Conference

## The AT Odyssey Continues

June 22-26, 2001

John Ascuaga's Nugget Hotel
Reno, Nevada

Richard Simpson, PhD ATP
Editor

Ken Kozole
Jeff Symons
Conference Co-Chairs

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## Foreword

On behalf of the local committee we would like to welcome you to Reno for the RESNA 2001 Annual Conference! This year's theme entitled "RESNA 2001- The A.T. Odyssey Continues" suggests that our quest for the latest information regarding assistive technology and its application is a continuous adventure. With that goal in mind, RESNA offers a unique opportunity for those who attend the annual conference. Not only are attendees provided with a variety of learning experiences, but also the opportunity to network and share information with others who share the same challenges. In an effort to make the 2001 Conference the best, we asked others and ourselves: "Why do you come to RESNA?" The answers were varied, but we found mostly people come for the courses, the presentations, the exhibits and to connect with colleagues. We solicited people about the type of courses and presentations they preferred, and the kind of exhibitors they wanted to see. As a result, many RESNA members went the extra mile to make sure we could offer these learning experiences and exhibitors. A big part of your learning experience is in the Exhibit hall. Come and see how our special emphasis on getting you the most innovative and leading edge information from manufacturers and research groups resulted in a full hall of exhibitors.

As conference Co-chairs we feel that our job is to make sure you all have a great conference. If there is anything we can do to make the conference better for you, please let us know. You can leave a message at the RESNA main desk, leave a message at our rooms or page us. We hope you'll find the conference exciting, informative and fun! Reno and the surrounding area have much to offer. Get some friends, take a break and visit the local area, attractions, shows, and Lake Tahoe. We hope that you will find this conference interesting, useful, and fun. ENJOY!

Ken Kozole
Jeff Symons
RESNA 2001 Conference Co-Chairs

Mary Binion
RESNA President

# Preface

Welcome to RESNA 2001. This year's conference includes over 200 presentations on all facets of assistive technology through concurrent sessions, scientific platform sessions, interactive poster presentations, computer demonstrations, and the Research Symposium.

This Proceedings of the RESNA Conference attempts to capture some of the information that will be exchanged during the activities and events of the Conference. The scientific papers included in this document contain everything from recent scientific research to practical designs to case studies. Scientific content is grouped into 8 categories:

- Technology for Special Populations
- Augmentative and Alternative Communications
- Computer Access and Use
- Environmental Accommodations
- Functional Control and Assistance
- Service Delivery & Public Policy
- Research and Functional Outcomes
- Seating and Mobility

In addition, the winning papers for the Student Scientific Paper and Student Design competitions are also included.

RESNA 2001 resulted from the efforts of many people. Tony Langton, in particular, has led the planning and organizing at both the local and national levels. Thanks go to Brenda Sposato, coordinator for the concurrent sessions which parallel the scientific sessions, and to the topic coordinators for the review process of the scientific papers: Alex Mihailids, Kevin Caves, Ivanora Alexander, Marty Blair, John Goldthwaite, Tariq Rahman, Shirley Fitzgerald, and Mark Schmeler. Thanks also go to the numerous reviewers of the individual scientific papers for their efforts in determining the final program. Jack Winters and Charlie Robinson are to be commended for their leadership in shaping the Telecommunications Research Symposium. As always, the efforts of Susan Leone are greatly appreciated, and Larry Pencak has proven to be a tremendous addition to RESNA.

Enjoy the Conference.

Rich Simpson, PhD
Chair, Scientific Program

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**Service Delivery and Public Policy (Topic 6)**

**Quantifying Function and Outcomes (Topic 7)**



**Seating and Mobility (Topic 8)**

# Technology for Special Populations (Topic 1)

# THE COACH: AN INTELLIGENT CUEING DEVICE FOR ASSISTING PEOPLE WITH DEMENTIA

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## ABSTRACT

The COACH-- Cognitive orthosis for assisting activities in the home, is an intelligent cueing device that is being developed to help people with dementia during their activities of daily living. The device uses artificial intelligence to "watch" the user and his/her surrounding environment, learn from his/her actions, adapt to individual preferences, and issue varying levels of cue detail. This paper will focus on the rationale behind this research, and describe the device's development.

## STATEMENT OF PROBLEM / RATIONALE

It is estimated that one out of three people over the age of 85 has dementia [1]. Dementia is characterized by a decline in cognitive function and memory, and often results in an affected person not being able to complete activities of daily living (ADL) because he/she becomes disoriented and confused. A common solution is for a caregiver to constantly watch the person, and provide verbal reminders when necessary. This loss of independence and privacy can be especially upsetting for toilet-related activities.

It is hypothesized by the authors that independence can be improved through the use of an intelligent computerized device that provides reminders needed by the user, and monitors his/her progress during an ADL.

## BACKGROUND

A computerized cognitive device, or prosthesis/orthosis, can be used to assist people with brain injury through ADL and vocational tasks by providing cues and audible alarms [2] [3] [4]. However, there is virtually no literature that describes such devices being developed for people with dementia except for results published from a pilot study conducted by the authors. In this study it was shown that a user with moderate-to-severe dementia completed an ADL task (handwashing) in response to a computerized device that used a recorded voice for cueing [5].

A cognitive device must be adaptable. It needs to be able to handle variations not only in how its user completes an activity, but in how the user might fail as well. The majority of previous devices achieved this through input from the user, and/or by manual re-programming of the software by either the user or a caregiver. These actions are less likely to be completed by a person with dementia or a more severe cognitive disability. To be effective for this population a cognitive device must be able to adapt automatically and on-line. Perhaps artificial intelligence (AI) techniques can be used to incorporate this more effectively than past devices.

## DESIGN

The design objective was to create a device that uses AI programming techniques to intelligently and rationally guide a person with dementia through an ADL task, and that can automatically adapt its strategies to best assist its user. This resulted in a prototype of a computerized device—the COACH. Figure 1 shows the general architecture of the COACH.

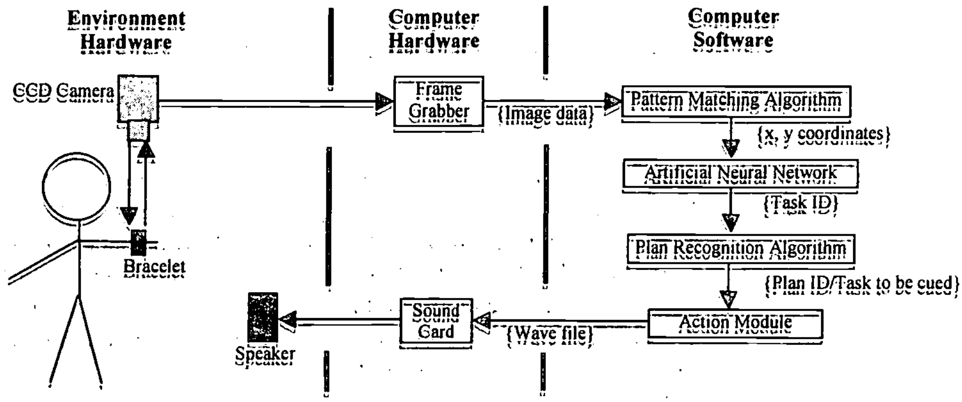


*Figure 1 - Architecture of the COACH*

**DEVELOPMENT**

The COACH consists of a hardware component that tracks the actions of the user, and a software component that analyzes these inputs and makes decisions.

The hardware consists of a monochrome charged-coupled device (CCD) video camera that is located above the workspace. This camera is connected to a frame-grabber card (IMAQ-1408 from National Instruments[1]) located inside the computer that runs the device software. In addition, a mat comprised of a series of switches is located on the floor in front of the counter. This mat lets the device know whether the user is standing at the sink.

The software was developed using Labview v.5.1[1] and Matlab v.5.3 [2]. There are three main algorithms in the software—the **artificial neural network (ANN)**, the **plan recognition algorithm (PRA)**, and the **action module (AM)**. In addition to these three modules, a pattern-matching algorithm is used to track the position of a unique marker that the user wears around his/her wrist (a bracelet). Using this algorithm and the images from the camera, the x and y coordinates of the pattern are calculated and provided to the three main algorithms.

The ANN uses probability theory to "learn" which tasks correspond with various inputs from the environment (i.e. spatial coordinates of the user's bracelet/hand). The network classifies the inputs into task identification numbers, and allows easy training of the device for any ADL task by using training data acquired for the activity being performed. Using the output from the ANN, the PRA then determines which plan (i.e. which sequence of tasks), the user is completing, or predicts which plan the user is attempting in order to correct his/her actions. Finally, the AM is responsible for selecting and playing a pre-recorded verbal cue only when necessary. It has the capability of playing several different verbal cue details to the user for a particular task before assistance from a caregiver is required. Moreover, the selection of the required cue detail is based on an individualized performance history, which allows the device to learn about the user's abilities, tendencies, and habits. The performance history is a running average of the user's success rates for each individual task in the overall activity.

In addition to using spatial coordinates, the velocity of the user's hand is also calculated in an algorithm prior to the modules described above. This additional input allows for a rudimentary low-pass filter to be applied to the data. This filter ensures that data points collected while the

[1] National Instruments: Austin, Texas, (512) 794-0100
[2] The Mathworks, Inc: Natick, MA, (508) 647-7000

user's hand is in transition are not passed from the pattern-matching algorithm to the remaining software.

## PRELIMINARY EVALUATION

Testing with surrogate users during an example of an ADL, the handwashing task, is being completed to remove any bugs that may exist. Preliminary data regarding the device's operation has shown it performing at approximately a 90 percent success rate with respect to its ability to classify inputs from the environment, and correctly guide a user when a mistake has been made. This efficacy rate will improve as more refinements are made to the device's algorithms.

Evaluation of the device with several actual users (during handwashing) using a single-subject research design will be completed in the near future.

## DISCUSSION

To date the COACH can be trained to monitor a user during an ADL task using unobtrusive methods, provide varying levels of cue detail depending on the user's past performance, and automatically adapt it's cueing strategy to fit the user's habits and preferences (as long as these habits are correct).

The preliminary evaluations have shown that some improvements still need to be made to the software, specifically in improving its efficiency. These evaluations also indicate that more training data will be required than initially thought in order for the device to fully monitor and assist a user through any task or situation during the handwashing activity. The exact amount of data and number of trials that will be required is still to be determined.

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# MODEL FOR THE FUNCTIONAL APPLICATION OF ASSISTIVE TECHNOLOGY: COGNITIVE LIMITATIONS

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**ABSTRACT:**
In order to effectively apply assistive technology (AT) interventions, the AT provider must look beyond the diagnosis and assess the functional abilities and limitations of the person needing assistance. This paper proposes a model to help AT providers move beyond categorical diagnoses of cognitive limitations and focus on four common areas of cognitive functional limitations: Perception, Expression, Memory, and Processing. By focusing on these areas of function, the AT provider will be better able to identify the appropriate type of assistive technology intervention.

**BACKGROUND:**

The effective application of assistive technology (AT) for any disability requires the consideration of many different elements. Before an AT provider can effectively make a recommendation, they must consider the tasks involved, the abilities and preferences of the person who is to complete the tasks, and the environment in which the tasks will be completed (1, 2). This information may be gathered (and should be confirmed) through multiple sources. In an effort to provide timely service, AT providers may find themselves relying too much on the stated diagnosis to provide guidance in the recommendation of AT. The stated diagnosis often encompasses a broad range of functional limitations and abilities that vary greatly between people. Therefore, in order to identify the person's abilities, the AT provider must purposefully shift their focus from the categorical diagnosis (e.g. learning disability, blindness, spinal cord injury, etc.) to the functional limitations of the person before recommending AT intervention.

This paper presents a model for the functional application of assistive technology in regard to **cognitive limitations.** Cognitive disabilities are the source of disabling conditions for many people with disabilities. In 1992, the category of learning disabilities and mental retardation alone accounted for 2.6 percent of disabling conditions for people in the United States (3). The model will help guide the AT provider to the appropriate *type* of AT device for specific cognitive functional limitations. This model may also help referral sources understand how to provide clearer descriptions of the person's situation in initial referral documentation, thereby speeding up the service delivery process.

**OBJECTIVE:**

Although the etiology for each of the diagnosed cognitive disabilities (e.g. stroke, acquired brain injury, learning disability, etc.) is different, there is significant overlap in functional limitations. The objective of the model is to categorize the functional limitations of various diagnosed cognitive impairments in such a way that an AT provider may quickly and accurately focus on the appropriate type of AT interventions.

**METHOD:**

When making a recommendation for AT intervention, it is important to consider the tasks that the person is trying to perform. It has been shown that, for the purpose of problem solving, humans may be represented as information processing systems. In the model presented by Simon and Newell (4) "input" was considered to be the sensory system, "output" was the motor system. However, the categories in system are too broad to effectively lead an AT provider to appropriate AT intervention. Focusing only on the cognitive function while using the same computer analogy, the corresponding areas of are Perception (input), Expression (output), Memory (storage), and Processing (change). The description of each category is as follows:

**Perception (Input)**

Perception refers to a person's ability to understand information that is accurately sensed. A person who has no sensory impairment (i.e. no hearing or vision loss) or has had the sensory loss corrected with the use of assistive technology may still have difficulty decoding the information received from the sensory organs. In this sense the "input" into the brain is affected.

**Expression (Output)**

Expression refers to a person's ability to demonstrate his or her thoughts or feelings both through verbal and non-verbal means. An expressive functional limitation may restrict a person *from* expressing himself or herself as intended or it may cause a person *to* express himself or herself in ways that are not intended or are not appropriate.

**Memory (Storage)**

The problems with memory fall into two basic categories: *storage* and *retrieval*. Storage refers to the act of developing specific neural pathways that will retain specific information that has been perceived. Retrieval refers to the act of locating the specific neural pathways, which lead one to the desired information.

**Processing (Change)**

Processing refers to a functional limitation that prevents a person from making use of the information that they already have or from going through the necessary "process" of obtaining information.

By assigning appropriate functional limitations to each of these four categories, the AT provider is encouraged to identify the manifestation of the diagnosed disability. Table 1 shows the functional limitations for each category. Each of the functional limitations leads to a particular type of assistive technology or compensation strategy. For example, a person with a learning disability who's functional limitation is visual perception may benefit from text-to-speech software. Whereas a person with a learning disability who's functional limitation is dysgraphia may benefit from a standard word processor.

TABLE 1

| PERCEPTION | EXPRESSION | MEMORY | PROCESSING |
|---|---|---|---|
| • Receptive Aphasia<br>• Visual Perception<br>• Auditory Perception | • Expressive Aphasia<br>• Dysgraphia<br>• Cognitive Motor Dysfunction<br>• Behavioral Expression | • Visual Memory<br>• Auditory Memory<br>• Procedural Memory<br>• Amnesia | • Attention and Concentration<br>• Executive Functions<br>• Visual Processing<br>• Auditory Processing<br>• Dementia and Mental Retardation |

**RESULTS:**

This process was described in an assistive technology handbook that was presented to 19 State Vocational Rehabilitation AT Providers and 2 State Vocational Rehabilitation AT Managers. The handbook also showed how diagnosed disabilities such as LD, ABI, and Stroke could result in various combinations of the functional limitations listed above. Based on the specific functional limitation, the handbook directed the AT provider to a list of appropriate types of AT and compensatory strategies. After reviewing the document, these providers were surveyed and asked to comment on the benefits of this model, in addition to other features of the handbook. Results and comments from that survey will be available for presentation at the RESNA 2001 conference.

## DISCUSSION:

The key to successful application of assistive technology is to understand the person's abilities, disabilities, and the specific task that is being attempted. One should always be cautious about trying to "categorize" people with disabilities or using a "formula" to assign appropriate assistive technology solutions. This model however, seeks not to categorize the people but rather to group like functional limitations in such a way that it will naturally lead the AT provider to likely options for AT intervention. For example, Mental Retardation was listed with Dementia under "Processing", because the functional limitations associated with Mental Retardation are similar to those of advanced Dementia. Therefore, AT intervention should stem from the same type of technology.

A similar model could also be developed surrounding the topics of sensory impairments or mobility impairments using different categories. These models are useful not only to guide the AT provider, but they also help paint a broad picture of AT intervention that can be useful as a training tool for those less familiar with AT. It is important to note that the provider must not neglect to perform a thorough evaluation and consider all aspects of the person's abilities, mobility, sensory, cognitive, and psychological before attempting to recommend an AT intervention.

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# BLIND NAVIGATION USING RADIO FREQUENCY IDENTIFICATION TAGS

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## I. ABSTRACT

Efforts to use technology to provide navigational aids for blind people divide themselves into two groups. The first involves the avoidance of obstacles or dangers in the immediate environment. The second type is navigation to a location, providing information about the user's current position and a route or at least a direction to a destination. Some of these use Global Positioning Satellites (GPS) to provide large area navigational support. Others base their operation on local, location-specific infrared transmitting signs. This paper proposes the development of an extremely inexpensive, highly accurate solution that operates well within the workplace, public settings, or large cities using radio frequency identification (RFID) tags to provide navigation data.

## BACKGROUND

GPS Based Systems

The GPS system depends upon twenty-four global positioning satellites orbiting the earth that can transmit messages to GPS receivers. Receivers determine their position by taking the difference between the time stamp in the message and the local time in the receiver. The receiver must communicate with at least three satellites to obtain a two dimensional fix and four satellites for a three-dimensional fix. GPS does not work well in urban settings, particularly along sidewalks next to buildings that block and bounce the satellite signals. Moreover, it does not work at all inside the buildings where people spend most of their lives.

The picture at the left, an A-1 Electronics prototype, is an example of current GPS system packaging. As the effort to reduce the size of the unit proceeds, a cell phone containing a GPS receiver will probably evolve. It could be used to connect to a central fixed site where a server will provide the Geographic Information System (GIS) database, speech recognition, text to speech, and differential GPS position information.

*Advantages of GPS Navigation Systems*

- Data is available to any device that can receive the signal.
- Rich geographic information system databases have been developed

*Disadvantages of GPS Navigation Systems*

- GPS does not work indoors nor outside if surrounded by tall buildings
- Signal error too high for walking with starts, stops, and turns
- Commercially available geographic information systems are not rapidly updated with information needed by pedestrians.

An Alternative: Infrared Receiver-based Systems

So-called "talking sign" systems transmit data via infrared from a fixed position to receivers that can be tuned to receive navigation information. While the infrared receiver can provide users with implicit orienting information, by the same token, they can only receive navigational information if they have already aimed the receiver at the sign. Crandall (1) describes and critiques the use of "talking signs" on streets and crosswalks surrounding a subway station in San Francisco.

*Advantages of Infrared Navigation Systems*

- Operate well both indoors and out, subject to line-of-sight constraints
- Signal reception provides the user with orienting information.
- Information carried by signals can be updated to reflect environmental changes.

*Disadvantages of Infrared Navigation Systems*

- Signs require a power source
- Improper orientation or aim can miss signals entirely
- Navigation is limited to the signs that can be seen.

According to Crandall (1), the San Francisco experiment has been the only infrared-based implementation for navigational use by the blind in the context of a public service.

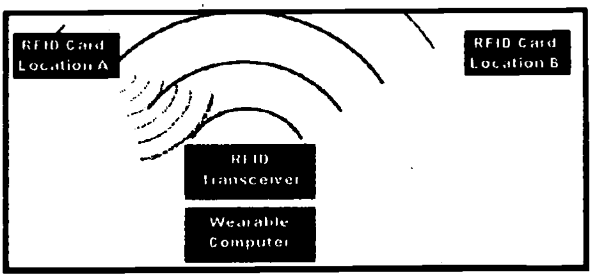
## A RADIO FREQUENCY IDENTIFICATION-BASED SYSTEM FOR NAVIGATION

Radio Frequency Identification (RFID) systems normally use mobile tags and fixed transceivers, such as are found in automatic automobile toll payment devices. We invert this normal order of things, having the blind user carry a transceiver through fields of stationary tags.

RFID tags do not require a conventional power source as they transmit data in response to a signal sent from a transceiver. This keeps their costs low, around one dollar each, and widespread commercial applications continue to reduce even this cost. Low power limits the transceiver range to nine feet, so navigation system could be implemented by populating an area with tags along corridors, offices, and waypoints within or among buildings. This approach will provide businesses and government agencies with a low-cost avenue to access by persons with visual disabilities. Positioning tags numbering, at most, in the hundreds can provide navigational independence. The more expensive transceivers could be supplied only to those needing them while at the site.

Because the tags are programmable, they could contain not only location coordinates, but other limited information to support navigation. However, it is most likely that the tags would be used to supply a portable computer with an index into a database of richer, easily updated information that could include paths to emergency exits, telephone numbers, changes to the physical environment, or personal navigation routes.

The figure to the right illustrates components of a RFID navigation system. Tag A has been excited by the transceiver signal and is broadcasting its data to the transceiver. Tag B is out of range, but the computer might be able to interpret the fact that A can be sensed, but B cannot.




*Advantages of RFID-based Navigation Systems*

- Can be used where people spend the most time, indoors or out.
- The tags require little investment and maintenance and no power.
- Complexes of tags can provide rich data for navigation.

*Disadvantages of RFID-based Navigation Systems*

- Tags must be positioned and programmed.
- Single tags cannot orient users unless combined with other environmental information.

## PROGRESS ON AN RFID-BASED NAVIGATION SYSTEM

We have been concerned with identifying how well RFID technology can be adapted to situations where the transceiver moves and the tags do not, handling uncertain signal reception, and inferring from observations of complexes of tags.

The components permit tags to be read by the transceiver when they appear within an arc of 45° with a radius of approximately nine feet. As a person walks with the transceiver through an area populated with tags, they appear or disappear to the transceiver as they move into or out of its reception arc. Movement and orientation of the transceiver affect tag visibility, as do variable tag signal strength and the reflection or absorption of signals nearby objects.

The appearance and disappearance of tag signals requires cautious interpretation. For example, transient tag signals detected by the transceiver may have been reflected from a metal door down the hall. Information about the consistency of a signal can be analyzed by itself as well as in terms of prior knowledge about current position and tag geography. For instance, if the navigation application has confidence that the user is at a particular point and a signal arrives from a tag that is known to be thirty feet away, the system will assign that signal low validity.

Similarly, the appearance and disappearance of legitimate tag signals enable the monitoring application to hypothesize about a user's movement along a path. To do so successfully, the application must be *geographically self-aware*, that is, it must maintain estimates of its possible positions validated against a prior model of tag geography. We are beginning to understand all the meta-geographic information with which that model must be augmented, such as common user goals (e.g, "the way to the cafeteria with the fewest stairs") or connectivity (e.g., "tag 27 and 28 can be sensed together from a position near tag 26, but 28 cannot be reached by walking").

The system needs to support a range of user interfaces depending on the users' capabilities and usage context. We are developing it to be useful for workers to support activities such as building maintenance or equipment inspection where geographical or spatial contexts are critical to the storage, retrieval, and interpretation of information. Non-visual interfaces (2) will be generated for those uses and users that require them. That work lies beyond the scope of this communication and will be explained in future ones.

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# LEARNING DISABILITY, THE INTERNET AND SELF: A ROLE FOR AT PROFESSIONALS?

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## ABSTRACT

This paper reports a survey of personal home pages written by people with Down's Syndrome and investigates the extent to which they use the pages to explore or express their identity. Opportunistic sampling of the pages listed by five Internet Service Providers revealed twenty personal home pages of adults with Down's Syndrome. Thematic analysis of the content, form and language of the pages revealed similarities and differences in the way the page owners expressed and perceived their self-identity. The results suggest that the personal home page has the potential to allow adults with Down's Syndrome to express multiple identities: identities that are the same and different to other people with Down's Syndrome.

## BACKGROUND

When people with a learning disability reject the label "learning disability" it is argued that they are not denying that they have a particular learning disability, they are denying that they are less worthy than non-handicapped people [1]. Furthermore, people with learning disabilities may manage their identities and vary them according to local, contingent or interactional reasons. In other words, their identity may not be static [2].

The Internet is rapidly becoming accepted an element of computer culture that enables us to think about identity and produce "narratives of self"[3]. The style, structure and vocabulary of a page may reveal unintentional information about identity [4]. Personal home page authors can use different building blocks to produce very different kinds of home pages, which in turn may project different images or identities [5].

The Internet may enable people to manage their identity by allowing them to acknowledge their group identity and share their experiences with people in identical circumstances [6]. Conversely it can also offer an opportunity for disabled people not to have to acknowledge how different they are to the rest of the population [7]. Whether or not the Internet has the potential to allow people with disabilities to manage their identity is likely to depend on a number of factors including technical skills [8].

This paper will report the results of a survey of personal home pages written by people with Down's Syndrome and investigate the extent to which they used the pages to explore or express their identity.

## RESEARCH QUESTION

Are people with Down's Syndrome using home pages as a tool to express or explore their identity.

## METHODOLOGY

The sampling methodology used in this study involved opportunistic sampling. The pages of five Internet Service Providers were sampled. The keywords used to conduct the search were learning disabilities, mental handicap, mental retardation and Down's Syndrome. Of the pages sampled, a home page was included in the study if it met the following criteria:

- The page belonged to someone with Down's Syndrome. This was by explicit reference e.g. "I am Down's Syndrome" or through explicit referral from another page e.g. " this page belongs to my friend who has Down's Syndrome"
- The page belonged to someone aged thirteen or over and therefore could be defined as an adult (by explicit reference e.g. " I am 23" or indirect reference to adult activities such as college or work)

A simple thematic analysis of all text, links and images was conducted in order to try and categorise the home pages.

## RESULTS

The opportunistic sampling technique revealed twenty personal home pages that met the inclusion criteria. A thematic analysis allowed the pages to be placed into three main categories:

1. This is me, I am a member of a family and the Down's Syndrome community
2. This is me, I a member of the Down's Syndrome community
3. This is me, I am a member of a family

The home pages in the first category contained Personal, Family and Down's Syndrome information. Six of the twenty home pages sampled fell into this category. They tended to be bigger than other pages in terms of how many images and links they contained. Five of the home pages were sole sites and not part of a bigger site (e.g. family) four of the six home pages included a personal email address.

The pages in the second category contained Personal and Down's Syndrome information. Five of the twenty home pages sampled fell into this category. Four of the five home pages had more external links than internal links and the nature of these external links was a mixture of personal interests and Down's Syndrome or disability information.

The pages in the third category contained Personal and Family Information. Eight home pages sampled fell into this category. All eight pages referred minimally to Down Syndrome. Five pages included photographs of family members. Seven of the home pages were hosted by a family web site and five home pages included the email address for a family member.

## DISCUSSION

All twenty home page owners acknowledged membership of the Down's Syndrome group to some extent. Indeed if they had not, it would have been more difficult to find the pages in the sampling process. The page owners acknowledged their membership of the Down's Syndrome group by either providing direct statements and descriptions, photographs of themselves or links to Down's Syndrome information. In doing so, these people do not appear to be stigmatised by their label of Down's Syndrome or denying group membership. The different categories that the home pages fell into suggest that the home page owners are using their home pages to construct and present multiple selves.

However, care needs to be taken in interpreting whether the self being presented is how the person actually since eight of the twenty pages were written in the third person. In a lot of the cases it is clear that the "third person" was a family member. One possible reason why so many pages were written in third person is that the person with Down's Syndrome may have technical difficulties in authoring and publishing web pages themselves. They may therefore rely on their relatives to author and publish their pages on their behalf. This may explain why seven home pages were part of a family web site and five home pages included the email address for a family member rather than the person themselves.

It may therefore be useful to explore the extent to which AT professionals could provide technical assistance in the self-presentation process without overly influencing the nature of the "self" that is presented. Such assistance might involve advising on alternative access devices, providing web-authoring training or hosting home pages.

## CONCLUSION

The results suggest that the personal home page has the potential to allow adults with Down's Syndrome to express multiple identities. Further work needs to be done however to investigate how adults with Down's Syndrome may be helped by AT professionals to take more control over the construction and presentation process. In providing such assistance AT Professionals may challenge their own sense of professional identity and purpose.

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# EVALUATING THE RESPONSE OF CHILDREN WITH AUTISM TO A ROBOT

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**ABSTRACT:**
Since 1998, the Aurora project has been investigating the use of a robotic platform as a tool for therapy use with children with autism. A key issue in this project is the evaluation of the interactions, which are not constricted and involve the child moving freely. Additionally, the response of the children is an important factor which must emerge from the robot trial sessions and the evaluation methodology, in order to guide further development work.

**BACKGROUND:**
The term autistic spectrum disorder (ASD) encompasses a range of disabilities and includes Pervasive Developmental Disorder - Not Otherwise Specified (PDD-NOS), Aspergers Syndrome and the diagnosis of autism. Depending on the designation, ASD affects between five and fifteen people in every ten thousand. The effects vary considerably between people, but common symptoms are hyper-sensitivity, learning and developmental problems and problems and avoidance of social interaction. The National Autistic Society state three main symptoms of autism, which they term the 'triad of impairments'. These are deficits in 1) social interaction, 2) social communication and 3) imagination and generalisation. While autism is a life-long disability, a number of therapy programs exist to help the person to cope with daily living. One of the most popular of these is the TEACCH program (Treatment and Education of Autistic and related Communication handicapped Children) [1] which centres on a philosophy of promoting pro-active behaviours by using unrestricted learning and positive reinforcement.

**THE AURORA PROJECT:**
The Aurora project (Autonomous Robotic Platform as a Remedial Tool for Children with Autism) [2, 3, 4] was started in 1998 to investigate the use of a robotic platform as an aid to the therapy of children with autism, specifically in the area of social interaction and communication. In line with the TEACCH program, where situations are presented to the child who is able to respond, it was thought that a robot would allow the child to interact in an unrestrained manner. Also, it was thought that a wheeled robotic platform would be most familiar and reassuring for the children, due to television and similarities with vehicles.
In the long term, the project aims to provide an additional method of therapy and learning for the teachers of autistic children. Short term goals of the project are to allow the children to experiment and interact with the robot and to gauge the response that this platform elicits from the children. One of the most challenging aspects of the project is to develop a methodology to evaluate the interactions between the children and the robot. Since the project does not aim to constrict the children in any way, both the robot and child are able to move around a room and to interact in any way that they are able. However, the unrestrained nature of the interaction makes evaluation of the effects difficult. In response to this, a micro behaviour analysis was developed, based on [5]. The next sections focus on methods and results of a comparative study involving the robot and a non-robotic toy.

## METHOD:

Robot trials take place in a room – approximately 2 meters by 3 meters – at a school for autistic children and the robotic platform used is robust enough for the children to push it around and play naturally. Four male children interacted with the robot, with ages ranging from 7 to 11 years and all where mid to high functioning. The robotic platform is 30cm by 40 cm and weighs 6.5kg. Eight infrared sensors allow obstacle avoidance and a pyro sensor to detects the children, while it is programmed with a library of behaviours such as obstacle avoidance and speech output. Average trials last for ten minutes, for four minutes the child was able to interact either with the robot, or with a similar size and shape toy truck, for two minutes both the toy and the robot (which is now turned off) are present and the last four minutes involve the toy or robot (whichever was not used previously). However, this plan is occasionally altered, by a teacher from the school, who is on hand in case the children become distressed and in order to observe when the child should end the interaction.

Trials are evaluated using the video record and each second of the video is analysed for a number of behaviour parameters, to quantify the interaction. The behaviour parameters used fall into two categories – the first category consists of behaviours where the focus of the behaviour is important, eg the child handling the robot or an object in the environment, and the second category consists of behaviours where the focus is indeterminate or less important, for example the child may say a phrase where it is difficult to determine the target. The behaviour parameters are:

Category One: *eye gaze, eye contact, operate, handling, touch, approach, move away, attention.*

Category Two: *vocalisation, speech, verbal stereotype, repetition, blank*

Operate (to use the robot by its sensors), handling (moving the object through force) and touch are grouped into a single category to represent the total contact time. Eye gaze attempts to describe what the child is looking at, while eye contact is judged as situations when the child looks at the perceived 'head' of the object (the heat sensor for the robot, the front windscreen for the toy. The blank parameter record the instances when the child is doing nothing or very little and notes are made to catch any behaviours which may be relevant but which are not otherwise covered.

## RESULTS:

| | | Touch | Handle | Operate | Seconds | Contact | Gaze |
|---|---|---|---|---|---|---|---|
| Child A | Robot | 26.33% | 42.70% | 0.00% | 452 | 69.03% | 81.64% |
| | Toy | 11.79% | 45.12% | - | 246 | 56.91% | 40.24% |
| Child B | Robot | 18.61% | 5.28% | 18.06% | 360 | 41.95% | 60.56% |
| | Toy | 3.33% | 57.22% | - | 360 | 60.55% | 71.67% |
| Child C | Robot | 11.26% | 72.64% | 0.00% | 435 | 83.90% | 93.33% |
| | Toy | 0.00% | 2.99% | - | 134 | 02.99% | 14.18% |
| Child D | Robot | 1.93% | 0.23% | 17.08% | 363 | 19.24% | 53.99% |
| | Toy | 19.33% | 37.67% | - | 300 | 57.00% | 60.33% |

*Figure 1: The percentage of time for behaviour parameters. Contact time is the total of touch, handle and operate.*

These results in figure 1 show that the robot and the toy have similar contact times, with two children having a higher percentage for the robot and two with the toy. However, the trial times are generally longer for the robot, indicating that the children are happy interacting with it.

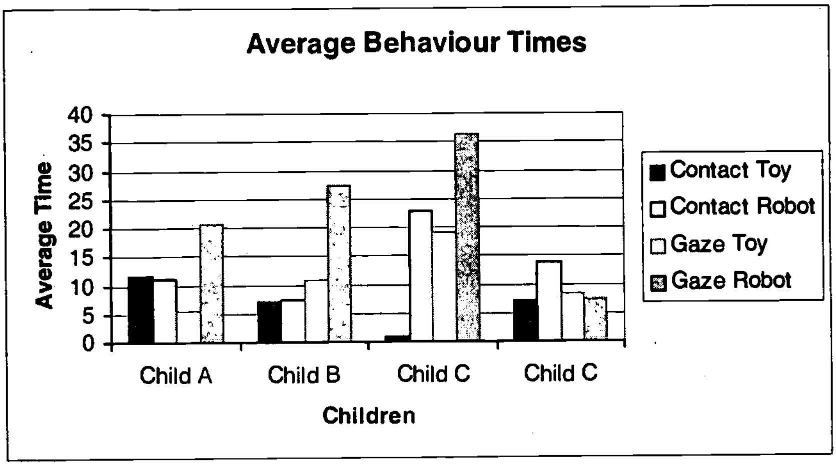


*Figure 2: The average time of behaviours for toy and robot.*

Figure two shows the average length of the behaviours, with most averages being higher for interaction with the robot. The results show that the children are not afraid of the robot and that they are able to interact and to play with it at ease. This quantitative characterisation of human-robot interaction patterns with individual children provides a foundation for further work in order to develop the robot as a therapy device.

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# TECHNOLOGY AND MULTIPLE SCLEROSIS—THE INSIDER PERSPECTIVE

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## ABSTRACT

People with Multiple Sclerosis (MS) often benefit from using technology to maintain or increase their independence and participation in employment, education, and recreation. In addition to mobility and vision problems, many people with MS also experience cognitive changes, such as difficulties with memory and word finding that could also be accommodated with technology. In this paper we present a case study of the issues around assistive technology confronted by a graduate student who also works as a programmer. He is reluctant to disclose his limitations, prefers to discover his own compensatory technology and accommodation, and does not seek professional assistance.

## BACKGROUND

Research teams at the University of Washington Department of Rehabilitation Medicine have conducted a series of qualitative research projects to study the "insider perspective on living with MS." In this paper we present a case study that in many ways highlights experiences and perspectives of a group of individuals we have interviewed. Our case study is of a 29-year-old male student who is enrolled in a graduate program in a scientific field and works as a computer programmer. Bill (this is not his real name) was diagnosed with MS five years earlier and reported that he has encountered significant barriers to his graduate study and programming related to cognitive changes (especially difficulties with memory and word finding), fatigue, unpredictability of symptoms, and significant changes in his vision.

Although over 95% of people with MS in various surveys have been employed at one time, at the time of the surveys (average time following MS diagnosis from 5 – 17 years), employment rates had dropped to approximately 25% (2), (3), (4), (5). Physical disability factors clearly play a key role in reducing access to employment, but environmental barriers and lack of accommodation in the workplace also serve as significant barriers to employment for people living with MS (8), (9), (11). Cognitive deficits have increasingly been found to be associated with higher rates of unemployment for people living with MS. At least half of the individuals living with MS will develop cognitive symptoms (6). Individuals with MS who have left employment are more likely to have cognitive deficits and are more likely to be isolated socially (6), (11). Assistive technology may be part of the compensatory strategies addressing all of these functional limitations to enhance participation in education, work, and community.

## METHOD

Qualitative methodology is well suited for research in when we seek to understand the perspective of individuals living with health conditions. We interviewed 22 individuals from throughout the Pacific Northwest for a minimum of one hour. Interviews were audio-taped and transcribed and the transcription verified. Transcripts were then coded by consensus among the research team and entered into the qualitative research software package Ethnograph (12). Themes that illustrate unique experiences of individual informants and perspectives shared across informants were then developed by consensus. For this presentation, we have selected one of the interviews that provides a valuable insight into the barriers faced by an individual with MS. We have adapted the qualitative methodology to study this case intensively and present quotations from the informant as data.

## RESULTS

Bill did not disclose his disability until it was impossible for him to hide the problems (especially the problems with his vision).

*"I used to TA quite a bit, and I'd write stuff on the board and I couldn't see it. If someone asked me a question about 'what does that say?' I'd have to sort of trick them into pointing me to where on the board. This was all prior to actually coming out with the disease. I tried to keep it a secret as long as possible."*

Once he decided to disclose his disability he used the disclosure itself as an accommodation.

*"I basically come out up front and let people know that I have these impairments, and that I will probably run into some problems given some of that."*

Bill seems to have discovered the features and strategies that allow him to function better on his own. It appears that he hadn't asked for any accommodations from the employer (such as working at home part time, a quiet room, or air-conditioning) even though heat, sensory overload, and light conditions make it difficult for him to perform at times. The main accommodation is that his work is flexible and he can take work home when necessary.

*"I can perform at my own progression, at my own speed. If there is a deadline it's not like I have to perform in the next few minutes. I don't have to get that order on the table in five minutes. I can take it home and work on it through the night where it's cool and it's dark, after a pot of coffee. I don't have someone breathing down my neck for the most part. If I take work home, it's like a time stop. I can do it right so then the next time they see me it'll be done."*

He learned about and uses the high contrast feature that helps him to see the computer screen better. This is a built-in feature of the Windows operating software that changes the display settings.

*"I've changed all my computers at work, at school, and at home to high contrast black background with white lettering. It helps a lot."*

Bill also uses word processing in many different ways to accommodate his memory problems, difficulties with writing and organization of writing, editing, etc.

*"I like the computer because you can cut and paste a lot. When you write down stuff on a piece of paper you have to remember that over here on this piece of paper I wrote down this important fact. I can't keep that in my memory. It's just too much."*

*"Right now I'm writing a program that involves filtering wave forms, and I have, of course, trouble remembering certain filter design equations. So I have to look those up and I'll write that on the computer, I'll just open up a blank text file and write down what I need to know. And then, with that text file and my program next to each other, I can go through my program and sort of insert that text in there."*

Many difficulties Bill experiences (particularly his inability to see his handwritten notes when he presents, or the need for reading large amounts of written material for his graduate studies) could be accommodated using technology, but due to his reluctance to ask for accommodations and to see a technology specialist these issues have not been addressed.

## DISCUSSION

Bill's case study illustrates issues that have frequently surfaced in our interviews with people with MS. Many interviewees have been reluctant to ask for accommodations and when they requested accommodation, they have wanted to be in charge of the process. Accommodations which are the least intrusive are preferred as Bill has chosen adaptations of off the shelf technology. Requesting accommodations for cognitive impairments has been viewed as unacceptable and seen as an admission of incompetence for most people with MS we interviewed and yet these functional limitations can be readily addressed through applications of assistive technology. Rehabilitation professionals working with people with MS may be able to serve the technology needs of their clients better by offering a range of options and allowing the user to set the pace and chose the kind of accommodations most acceptable to them. Creative uses of main stream technologies (display and magnification features, using word processors as memory aids) and showing them how to use email, paging technology, and word processors to accommodate their cognitive changes may increase the acceptance rate of technology interventions.

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# THE STAKEHOLDERS FORUM ON HEARING ENHANCEMENT

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## ABSTRACT

The Demand Pull Project on Hearing Enhancement facilitates the transfer of new and innovative technology into the hearing products marketplace. The Stakeholders Forum is a critical step in this Project at which important unmet customer needs and feasible technology solutions to address these needs are identified. Forum participants include manufacturers, researchers, clinicians, end-users and other stakeholders whose knowledge and perspectives are critical to the transfer process. The Forum is shown to be an effective means by which to identify unmet market needs and pre-competitive technology solutions desired by manufacturers.

## BACKGROUND

The Rehabilitation Engineering Research Center on Technology Transfer ($T^2$RERC), partnered with the Rehabilitation Engineering Research Center on Hearing Enhancement to conduct the *Demand-Pull Project on Hearing Enhancement* in 1999 - 2000. The goal of each Demand Pull Project is to facilitate the introduction of products incorporating new and innovative technology into the marketplace.[1]

This Project focused on four technology areas related to hearing enhancement: Earmolds, FM, Inductive and Infrared assistive listening systems (ALS) and Microphone technologies. The two RERC's hosted a Stakeholder Forum on Hearing Enhancement in New York City in June, 2000. Critical goals of the Forum included: 1) identifying important and unmet customer needs, 2) establishing that meeting these needs represent a significant business opportunity, 3) establishing requirements (function, performance, cost, etc.) for technology solutions to address these needs and 4) establishing that manufacturers are not likely to develop or obtain these technology solutions (by means other than technology transfer). Preliminary work by the $T^2$RERC included developing an Industry Profile and preparing White Papers for each technology area as a basis for discussion at the Forum. A consumer panel (8 technology users) and a series of expert interviews (10 researchers and 10 manufacturers) gave input for the White papers, which summarized customer needs, business opportunities, and an overview of each technology. They were reviewed for accuracy and completeness by a PhD audiologist under sub-contract to the $T^2$RERC and by staff at the RERC on Hearing Enhancement.

## METHOD

Technology transfer is the movement of a technology from Technology Developers (laboratory researchers) to Product Producers (manufacturers). Technology-transfer efforts will generally be unsuccessful unless: 1) Product Customers (end-users, clinicians) have significant, unmet needs; 2) Technology Developers identify feasible technological solutions to address these needs and 3) Product Producers are unable to develop or obtain this technology without assistance (e.g. high cost, lack R&D capabilities etc.). Resource Providers assist dissemination efforts, help to locate technology and provide funding.[2] It is therefore critical that Forum participants include appropriate representation from each stakeholder group.

The two RERC's worked together to identify highly appropriate Technology Developers and Product Producers for recruitment. End-users were recruited from advocacy groups (Self Help for Hard of Hearing, League for the Hard of Hearing) because of their knowledge of hearing technology and related issues. To help recruitment efforts, food and hotel costs were covered for all participants with transportation provided in selected cases.

Prior to the Forum, all participants received the white papers and a letter explaining the Forum process, their role in this process, expected outcomes and benefits to participants. The Forum conducted 8 focus groups (4 each day) to discuss the four technology areas. The number in each group varying between 13 and 20. Each attendee participated in two different technology groups. End-users were assigned to groups corresponding to their familiarity with and use of hearing technology. Other stakeholders indicated their groups of interest beforehand.

Each group session ran approx. 2½ hours, typically with two breaks. Each session's team consisted of: a moderator, a scribe (to record and summarize information), a technical person (to clarify points for the moderator) and a recorder (to summarize key points, assist with item ranking). To ensure full and equal access to the discussion, each room had a portable infrared assistive listening system (from Audex) with portable receivers and real-time captioning (also used to capture the full discussion). Pre-prepared scripts controlled the use of time and guided the protocols for each technology area. Moderators used a set of probing questions to ensure full coverage of customer needs, state of current technology, desired refinements and innovations, barriers to developing or obtaining technology and technology sources.

Participants evaluated each discussion session by answering survey questions on a 5 point scale (1=very poor to 5=very good). For each technology area, data for the two days were combined for analysis. To evaluate the overall Forum, participants were asked to complete a summative survey.

**RESULTS**

There were about 65 Forum participants (small variation is due to a few persons attending on single days) that included: Product Producers (8 hearing aid; 2 earmold; 2 infrared ALS; 2 inductive ALS; 1 FM ALS; and 4 electronic component manufacturers), Technology Producers (7 RERC-Hearing Enhancement, 5 advanced technology manufacturers; 5 other researchers), Product Consumers (13 end-users; 4 clinicians; 2 ALS installers) and Resource Providers (12). The 14 end-users (8 male, 6 female) ranged in age from 16 to 84 years. They reported having mild/moderate (5) or severe (8) hearing loss with 6 end-users claiming significant feedback problems. End-user technology use included: hand-held or body-worn microphones (6); hearing aids with T-coils (13); analog hearing aids (13); digital hearing aids (7); FM-ALS (9); and IR-ALS (7). All but one end-user was a member of an advocacy group (see Table 1).

| | **Earmolds** | | **FM** | | **IL&IR** | | **Microphones** | | **Total** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Day** | One | Two | One | Two | One | Two | One | Two | One | Two |
| **Product Producers** | 3 | 5 | 5 | 3 | 6 | 2 | 4 | 9 | 18 | 19 |
| **Technology Developers** | 2 | 2 | 6 | 5 | 6 | 4 | 3 | 4 | 17 | 15 |
| **Product Customers** | 3 | 3 | 4 | 7 | 5 | 3 | 6 | 6 | 18 | 19 |
| **Resource Providers** | 4 | 3 | 3 | 4 | 2 | 3 | 3 | 1 | 12 | 11 |
| **Totals** | 12 | 13 | 18 | 19 | 19 | 12 | 16 | 20 | 65 | 64 |

**Table 1: Participant Distribution Across Groups**

Mean scores (out of 5.0) for the group sessions (Ear molds n=25; FM systems n=27; IR & IL systems n=25; Microphones n=28) include: "content was relevant" (4.0, 4.4, 4.2, 4.2); "addressed most important aspects of topic" (4.6, 4.1, 4.5, 3.9); "went into sufficient depth" (4.7, 4.0, 4.1, 4.0); "purpose of group was clear" (4.5, 4.2, 4.3, 4.1); and "discussion achieved its purpose" (4.4, 4.0, 4.1, 3.9). Positive responses from the summative survey (Technology Developers n=11; Product Producers n=9) include: "groups helped you identify new business opportunities" (TD 4, PP 6); "exposed you to new or innovative technology" (TD 10, PP 6); "helped identify new direction for product development" (TD 8, PP 9); "helped you identify needs for new technology" (TD 7, PP 5) and "gave you an opportunity to network with manufacturers, researchers, clinicians and others" (TD 11, PP 9). Participants also agreed that: "White Papers provided an appropriate background for the Forum" with mean scores of 4.5 for End-users; 4.7 for Technology Developers; and 4.3 for Product Producers.

A complete listing and detailed analysis of the Forum data is not possible in a short paper but is available on line at http://cosmos.buffalo.edu/t2rerc/demand.html. A brief summary of high priority technology needs follows:

**Earmolds:** computerized ear canal measurement (e.g. 3D laser scanning); automated earmold production (e.g. one-day turnaround, CAD/CAM); advanced materials (e.g. reverse thermal gels) and composite earmolds (e.g. multi-material, inflatable pneumatic, etc.). **Inductive ALS:** prefabricated modular loops (or mats); intelligent loop amplifiers (or driver/adaptors for general loop amplifiers); and 3D telecoils (or equivalent) for hearing aids and body-worn receivers. **Infrared ALS:** system for natural, small group communication; universal (FM/IR) portable receiver; narrow-spectrum diodes for IR receivers; low power, high efficiency diodes for IR transmitters; improved IR transmitter modulator circuit; and smart transmitter diodes (e.g. adjust transmission power in response to ambient IR level). **FM ALS:** universal personnel communication system consisting of a transmitter, repeater and receiver, would work with all hearing aids, headphones, and consumer products such as cell phones. **Beam-Forming Microphone Technology:** body-worn microphones; tabletop microphones (e.g. for ALS replacing microphones and wires); binaural hearing aids (with wireless bi-directional communication link); and improved directional hearing aids.

Afterward, forum data was integrated with prior work to generate Problem Statements. These represent specific technological refinements and innovations desired by manufacturers with consensus support from all other stakeholder groups. The statements were disseminated through proceedings, websites, newsletters, journal articles and email and phone contacts inviting solutions from Technology Developers. As technology proposals are received, the T$^2$RERC will screen and broker promising proposals to manufacturers in the hearing industry.

**DISCUSSION**

To determine whether the Forum is an effective means by which to identify pre-competitive technology needs, a number of simple questions can be asked. Were all stakeholder groups represented? Were appropriate participants recruited? These questions were addressed by the careful recruitment efforts outlined above. Were participants properly prepared? Was the Forum objective clear? Were the technology groups well run? Do participants believe that the Forum was effective? Survey results suggest that these issues have also been addressed. Overall, these preliminary results suggest that the Forum was an effective means by which to identify pre-competitive technology needs. Participants also cited many collateral benefits such as networking opportunities, exposure to new technology and ideas for new product development.

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# USING A PALMTOP PDA FOR REMINDING IN PROSPECTIVE MEMORY DEFICIT

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ABSTRACT Prospective memory failure often accounts for poor medication adherence. This study explores the possibility of using personal digital assistants (PDAs) to remind people with prospective memory failure. Preliminary testing in normals shows that PDA use reduces the number of timing errors while performing a set of scheduled tasks ($p<0.001$). These results suggest that off-the-shelf palmtop technology can serve as effective aids for reminding. It also provides a means to monitor performance.

BACKGROUND Medication nonadherence in the elderly and others can lead to morbidity and institutionalization. Reminding technology can be employed to increase the independence of the elderly and to reduce their required level of care. Previous studies (1) have used calendars, pill wheels, pagers(1), telephone systems(2), voicemail(3), laptop computers, and portable electronic devices in attempts to increase the medication adherence of those suffering from prospective memory failure. Most of these devices lack a logging function to record patient actions. Flannery et al.(4) used a reminding program for a laptop computer that logged the response of a subject to specific questions relating to medication adherence and allowed researchers and physicians to further analyze the data. The current study incorporates a similar log.

RESEARCH QUESTIONS This study attempted to determine if palmtop technology can serve as a reminding system for those with prospective memory failure. This study also examined the ability of the subjects to use an Internet webpage for giving feedback.

METHODS Two Palm V handheld devices and attachable modems formed the hardware of the reminding system. Since the supplied software provides no timestamped logs, we added On-Time-Rx (AmeliaPlex, Inc), a medication reminder program. We also added Palmscape, an Internet browser, to access the website designed for this project.

Four subjects tested the system during a two-week period. For a control week each subject compiled a paper task list with planned and completed action times. During each day the subject wrote the actual completion time on the list. The weeklong experimental period required subjects to program tasks with scheduled completion times into the On-Time-Rx reminding program. The PDA sounded an alarm at the assigned time, and the subjects reported their actions on the touch screen. Two subjects performed the control period first while the other two performed the experimental period first. There were two types of tasks. The first were tasks chosen by the subjects that they needed to complete, and the second consisted of tasks assigned by the researchers requiring the subjects to be attentive.

RESULTS The subjects provided a total of 626 trials. Each subject responded for seven days while using a PDA and seven days while not using a PDA.

The distribution of the deviations of response times from scheduled response time are shown below. Excluded are tasks for which there was no response or for which the time was not recorded.

| error (min) | no PDA | % | PDA | % | total | % |
|---|---|---|---|---|---|---|
| -180 - -61 | 14 | 4.3 | 0 | 0 | 14 | 2.4 |
| -60 - -31 | 11 | 3.4 | 0 | 0 | 11 | 1.9 |
| -30 - -1 | 45 | 14.0 | 5 | 1.9 | 50 | 8.6 |
| 0 | 106 | 32.9 | 155 | 59.2 | 261 | 44.7 |
| 1 - 30 | 93 | 28.9 | 91 | 34.7 | 184 | 31.5 |
| 31 - 60 | 30 | 9.3 | 11 | 4.2 | 41 | 7.0 |
| 61 - 180 | 23 | 7.1 | 0 | 0 | 23 | 3.9 |
| Total | 322 | 100.0 | 262 | 100.0 | 584 | 100.0 |

We define a success as a deviation of zero. Missed tasks were counted as failures, but tasks for which the time deviation was unknown were deleted from analysis. There is a strong association between rate of success and PDA use (Chi sq = 41.45, df = 1, $p < 0.001$).

| PDA | Failure | Success | Total |
|---|---|---|---|
| No | 227 (68.2%) | 106 (31.8%) | 333 (100.0%) |
| Yes | 112 (41.9%) | 155 (58.1%) | 267 (100.0%) |
| Total | 339 (56.5%) | 261 (43.5%) | 600 (100.0%) |

The impact of the PDA was different for the two subjects who used the PDA the first week as compared to the two who used it the second week. For those who used the PDA during the first week the success rates are similar for both weeks. For those who used the PDA second the success rate is better when using the PDA than when not. Order of PDA significantly modifies the impact of using a PDA (Chi sq = 39.12, $p < 0.001$).

| | Used PDA First | | | Used PDA Second | | |
|---|---|---|---|---|---|---|
| PDA | Fail | Succeed | Total | Fail | Succeed | Total |
| No | 90 | 84 | 174 | 137 | 22 | 159 |
| | 51.7% | 48.3% | 100.0% | 86.2% | 13.8% | 100.0% |
| Yes | 78 | 89 | 167 | 34 | 66 | 100 |
| | 46.7% | 53.3% | 100.0% | 34.0% | 66.0% | 100.0% |
| Total | 168 | 173 | 341 | 171 | 88 | 259 |
| | 49.3% | 50.7% | 100.0% | 66.0% | 34.0% | 100.0% |
| | Chi sq = 0.86, p = 0.35 | | | Chi sq = 74.47, p < 0.001 | | |

We divided the deviations into three categories. The first is -180 through -11 minutes which indicates doing the task early. The second is -10 through 10 minutes which indicates doing the task on time, and the third is greater than ten minutes which indicates doing the task late. There is an association between PDA use and type of deviation (Chi sq = 76.99, df = 2, $p < 0.001$). Using the PDA reduced the number of early completions.

| | Deviation in Minutes | | | |
|---|---|---|---|---|
| PDA | (< -10) | (-10 - 10) | (> 10) | Total |
| No | 48 (14.9%) | 162 (50.3%) | 112 (34.8%) | 322 (100%) |
| Yes | 3 (1.1%) | 219 (83.6%) | 40 (15.3%) | 262 (100%) |
| Total | 51 (8.7%) | 381 (65.2%) | 152 (26.0%) | 584 (100%) |

There were two types of tasks. One set was defined by each subject and consisted of things that s/he needed to get done. The other set was busy work that required the subject to be attentive. The type of task does not affect the success rate (Chi sq = 2.14, $p = 0.16$) nor the impact of PDA use on success rate (Chi sq = 0.01, $p=0.98$).

Subjects reported only slight problems through the interactive web form. We received daily reports during the experimental period. The subjects successfully used radio buttons, check boxes, dropdown menus, and text entry fields. Subjects reported the need for a confirmatory message following form submission and learning difficulties using Palmscape.

DISCUSSION We believe that the main reason that PDA use produced better results was the alarm that provided a stimulus as well as specific instructions for each task. The small improvement and the good overall error rate of the PDA first subjects suggests that the PDA may provide a habilitation or training function that persists at least a week. The logging function of the reminding program effectively gathered the data at no cost to the user. Such logs permit monitoring medication adherence as well as self-review by a patient. The Internet reporting showed that it can be used to report to a remote monitor or caregiver, but our subjects were familiar with the web. Limitations to the use of this technology include the need to train naive users and potential difficulty to use for people with limited dexterity or visual acuity. These results suggest that further testing is merited in target populations with prospective memory deficit.

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## AN INTERACTIVE MAZE GAME DEVICE FOR PRE-HANDWRITING EXERCISES

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**ABSTRACT**

Handwriting is an important skill. However, many children have difficulties with handwriting. They need a device that allowed them to practice fine motor control and hand-eye coordination before they learn to write. The device presented in this paper is a portable, easy to use system that uses maze solving as a pre-handwriting task. The device was tested with several special needs children at an elementary school. The children were eager to work the maze, and responded well to the feedback.

**BACKGROUND:**

For many years, humans have relied on writing as a way to record events and ideas, and as a way to communicate with others. As a result, having good handwriting skills is important.

Many children have difficulty learning to write properly, as a result of a physical or cognitive disability, poor hand-eye coordination, or poor motor control. Occupational or physical therapy for these children at an early age helps integrate the cognitive and physical skills needed for good handwriting (1).

A therapist in the Durham County school system (North Carolina) was looking for a pre writing task to help her special needs kids develop fine motor control en route to developing writing skills.

**STATEMENT OF PROBLEM:**

Before a child learns proper letter formation, they work on pre-handwriting tasks to develop motor control and hand-eye coordination. A commonly used pre-writing task is solving mazes because it encourages children to make small, controlled movements in order to stay within the maze pathway (2). Pre-writing tasks typically require feedback and prompts from a therapist, teacher, or parent. Alternatively, an assistive device could supply these prompts, which would increase the independence of the student. A pre-handwriting tool was needed that was simple to use for both teacher and student, portable, and able to keep the child's attention through visual and/or audio stimulation.

The teacher or therapist designs a maze on a PC using the accompanying software. They download it to the microcontroller, print a hardcopy of the maze, and attach it to the graphics tablet. The device then tracks the movement of the student through the maze. As long as the student stays within the pathway of the maze, they receive positive feedback. If they stray from the path, the device provides negative feedback. The maze game allows the student to work on fine motor control while having fun!

**DEVICE DESIGN**

As shown in figure 1, the prototype device consists of three main parts: a pair of microcontrollers that act as the "brains", a graphics tablet that tracks the movement of the user, and circuitry. The therapist wanted a device that was portable so that it could be used in a variety of settings. While a PC is required to design a maze and download it to the device, afterwards it can be used as a standalone device.

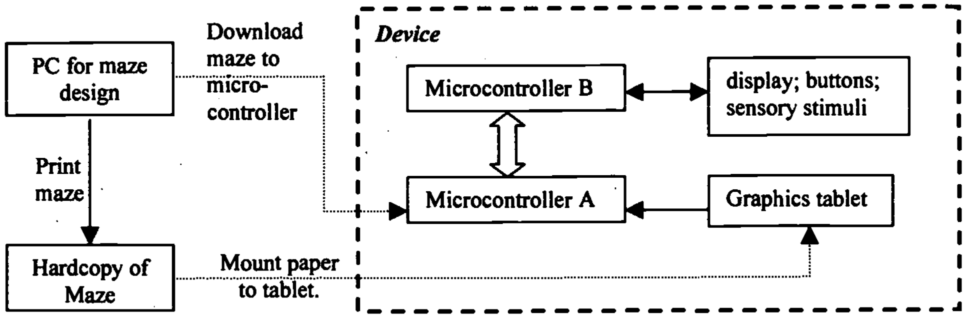


**Figure 1.** Block Diagram of System Control

The design of the device is divided into three parts: the programming of the maze design program on a PC; the programming for the Basic X microcontroller (Netmedia, Tucson, AZ, www.basicx.com) used to acquire data from the tablet; and the circuitry.

The goal for the programming of the microcontroller is to acquire maze design data from the PC, and to acquire and process the pen location data from the tablet.

The circuitry of the device incorporates all the components that provide the user with audio and/or visual stimulation: a buzzer, a music integrated circuit (IC), a voice recorder/playback IC with microphone circuitry, and LED's in the shape of a smiley face. In addition, the Wacom graphics tablet (Vancouver, WA, www.wacom.com) connects to the device via a serial port, as shown in figure 1.

## DEVELOPMENT OF DESIGN

The maze game is written as a separate piece of software that is used independent of the device. The program is written in Microsoft Visual Basic (Redmond, Washington). The teacher, therapist or supervising adult is presented with a blank 16 x 16 grid in which the user can click the mouse button once and then draw the desired shape of maze they want (Figure 2). The user can then save the maze for future use or modification. They can also print a hard copy of the maze to be used on the graphics tablet. And finally, they can download the maze to the microcontroller via the serial port of the computer. The printed hard copy and the download function are intended to be used together, as the microcontroller has to know the shape of the maze that the student working through. The maze program takes the maze grid and represents each square as a 1 or 0 based on the color of the square. For example, the first 8 squares in the first column of fig. 2 are represented as 11001110. The program then sends this binary data to the microcontroller where they are stored in the electronically erasable programmable read only memory (EEPROM). As the user solves the maze, the tablet sends the (x, y) data corresponding to pen location. The microcontroller uses calibration data to determine the relative location of the pen within the maze. The microcontroller then uses downloaded information on the shape of the maze to determine if the student is within the maze pathway.

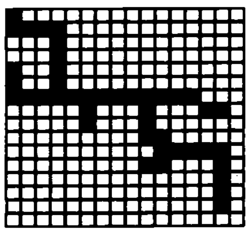

**Figure 2.** Representation of maze

Because of the complexity, two microcontrollers are used in the device (Figure 1). The microcontroller "A" is used to handle communication and data gathering from the tablet. This microcontroller guides the user through system calibration, so that the device can tell the orientation of the maze on the tablet. It also keeps track of the shape of the maze, and whether or not the user is staying in the pathways. The microcontroller "B" handles the menu driven user interface and the control of the stimuli. The user is able to choose which stimuli will be used for positive feedback and negative feedback. The two microcontrollers are in constant communication with each other, so the appropriate stimuli can be activated based on the performance of the student.

The microcontroller triggers activation of the sensory stimulation circuits, and interfaces with the button inputs and an alphanumeric LCD display. The LCD display and four buttons are used for a menu driven user input. They are mounted to the lid of a project box that housed the circuitry of the device.

## EVALUATION

The maze game was taken to Hillandale Elementary School where three different special needs children tried the maze under the supervision of the project's consulting therapist, Edie Kahn. Ms. Kahn designed a maze for the students using the software, and loaded it onto the microcontroller. The feedback was set so that the buzzer was used as negative reinforcement. The students seemed to enjoy using the maze. The versatility of the device was shown when it became apparent that one of the students actually liked to hear the buzzer go off. Then, the device was easily reconfigured to use the buzzer as positive feedback, which was appropriate for that student.

## DISCUSSION

With such importance placed on writing and writing skills, it is useful to have a device that allows students to independently enhance their fine motor skills. The device discussed in this paper is an easy to use, portable device that helps students practice an important pre-writing task.

In the future, the design of this device could be changed to handle multiple maze downloads, incorporate handwriting analysis, and increase the variety of stimuli.

## ACKNOWLEDGMENTS

I would like to take this opportunity to thank Dr. Richard Goldberg for his constant encouragement and support during the design. I would also like to thank Edie Kahn for her input into the design and for letting us play with her special needs children. I would like to thank Wacom for their donation of the writing tablet, and NSF grant BES 9981867 for financial support of this project.

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# DESIGN OF ASSISTIVE TRAINING STAIRS

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## ABSTRACT

Students who are physically or emotionally challenged often face difficult challenges when learning tasks such as washing dishes, opening doors, or even climbing stairs. It is the later task that this paper addresses. Stairs can be a very difficult challenge for disabled persons. Often stairs have different heights and sometimes there are no handrails. Disabled persons must face each of these different challenges. This paper outlines the design and construction of a training stair device that will meet the needs of physically challenged elementary school students.

## BACKGROUND

The Wyman Elementary School Developmental Pre-School in Rolla, Missouri is designed to provide students that have either physical or mental challenges with the extra support and education needed for them to succeed. The students, ages 4-5 years, have disabilities ranging from minor behavioral problems to severe physical challenges. These children not only face the challenge of getting an education, but they must also learn how to live in the real world. One major challenge for these students is learning how to climb stairs. Climbing stairs is a simple task for many people, but a very difficult task for these students.

The need for training stairs for physically challenged students is not a new problem. There are currently many products available for purchase that will satisfy the need of providing a device for students to learn to climb stairs on. What makes the training stairs that are currently available not applicable to Wyman Elementary School is some of the attributes that their training stairs must possess. For example,

- The Developmental Pre-School is currently located in a modular classroom, so the training stair device must require very little space.
- Being located in a modular classroom means that there is very little useable space, so the device must also be portable.
- The stairs must be quickly setup and taken down because the time students spend with the physical therapist is limited to only a few hours a week.
- The stairs must allow for different heights so the students can learn on a smaller height and then progress to larger more difficult heights.

With no current training stair possessing all of these attributes, the need for a new version of training stair is created.

## STATEMENT OF PROBLEM

The objective of this project is to design and construct a set of training stairs for the Wyman Elementary School Developmental Pre-School. After performing a market analysis and finding no products that currently satisfy all of the customers needs, it was determined that this is not only a viable design project but also one that will benefit mankind.

## PRODUCT DEVELOPMENT

The development of the training stairs consisted of four distinct phases (1). The first phase of which is *Clarifying The Task At Hand.* In order to clarify the task, the customers of this product were interviewed. The customers consist of a teacher, a physical therapist, an occupational therapist, and the students of Wyman Elementary Developmental Pre-School. Since the students could not be interviewed, they were observed while using their current training stair device. The students currently use a rocking boat (a semi-circular shaped toy with a seat on each end) for the children to practice climbing stairs. This device has only two steps, and no handrails. Some of the children have depth perception problems, and the fact that they can see the floor through the steps causes problems. The steps are not standard sized steps, so the children are not being exposed to everyday situations that they will need to cope with. Next, the therapists and teacher were interviewed in order to understand the problem and determine the customers needs. The customer needs were weighted on a scale from one to five with one being least important and five being most important. The top five customer needs are listed below in Table 1.

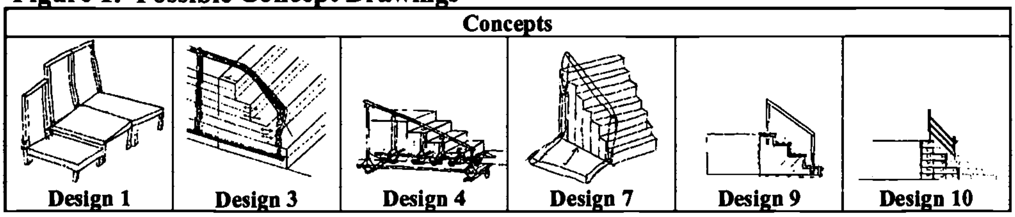
**Table 1: Top Five Customer Needs**

| Customer Need | Rating |
|---|---|
| 1.. Adjustable Stair Height | 5 |
| 2. Removable Handrails | 5 |
| 3. Adjustable Height Handrails | 5 |
| 4. Portable | 5 |
| 5. Non-skid Steps | 5 |

The second step in the design process is the *Conceptual Design Phase*. After gathering all the customer needs, the customer needs were related to functions that the training stairs must have in order to meet those needs. These functions were then combined into a functional model of the product. The functional model gives a form-free picture of all of the functions that the training stairs must perform. The functional model allowed for the generation of more creative concepts for the training stairs.

Next, ten different conceptual designs were developed to satisfy the customer needs gathered in the previous step of the *Conceptual Design Phase*. In order to determine which design to continue developing, a Pugh chart was used to select the best design among all of the designs. The Pugh chart was applied by first choosing a datum design, and then rating each design against the datum. Each design was rated using a specified set of criteria. Some of the concepts can be seen in Figure 1 below.

**Figure 1: Possible Concept Drawings**




Design 10 was selected from the Pugh chart. This design allowed an unlimited number of stair configurations because it was made up of many blocks, which could be attached to each other with Velcro. A scaled prototype of this Velcro design was made and shown to the customers. After a demonstration of the prototype, the customers did not approve of this design because they felt it would take too long to assemble. Thus we discovered the latent customer need of short set-up time, so the *Conceptual Design Phase* was revisited.

Since there is a new customer need, the Pugh Chart was recalculated in order to choose a design that fit the new customer need. A design similar to Design 3, shown in Figure 1, was chosen. The new design is very similar to bleachers in a gymnasium. This design was originally not chosen because of an estimation made about the cost of building materials. Originally, this design used a more costly slide design therefore making it rank lower than the original selection of Design 10 in the Pugh chart.

The third step in the design process is the *Embodiment Design*. Since the final design has been selected, structural analysis was performed to calculate the dimensions of the structural members. Following current building codes, all of the structural members of the stairs were sized to meet the loading conditions required in commercial buildings. Simple static plate and beam analysis were used to calculate the required values. From these calculations 3/4 inch pine boards, 2x4 s, and 1/2 inch plywood were chosen as the building materials. Wood was chosen as the building material not only because it met the structural requirements, but also because it is easy to build with. With the design chosen and the material selected, a prototype was built in order to test the feasibility of the design.

The final step in the design process is the *Detail Design Phase*. This phase of the design process consisted of determining the specifics about the manufacturing processes to be used and finalizing the detailed drawings. After testing the prototype, a 2-D AutoCAD assembly drawing was created to build the training stairs. Figures 2 and 3 below are two pictures of the training stairs.

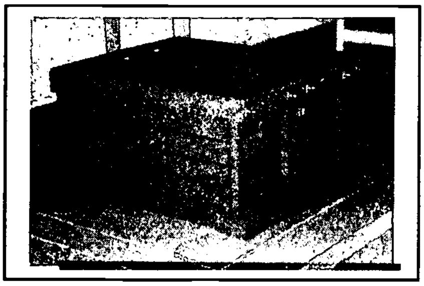


**Figure 2: Stairs retracted**

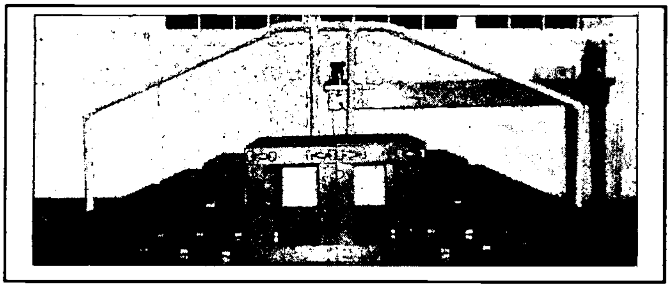


**Figure 3: Stairs deployed**

## DISCUSSION

The final design of the training stairs meets all of the needs specified by the customer. The completed stairs feature steps that slide in and out of a central unit, taking care of the set up time, height adjustment, and space requirements. Also, the central unit has wheels, making it portable. Finally, there is an abrasive paint applied to the surface of the steps to accommodate the non-skid customer requirement. Although only the top five customer needs are discussion herein, all of the customer needs were met. Therefore the design is a success.

## ACKNOWLEDGMENTS

We would like to thank Drs. Stone and McAdams, of the University of Missouri-Rolla, and Kathy Hrovat, of Wyman Elementary, for their help and guidance on this project.

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## DESIGN AND DEVELOPMENT OF A VESTIBULAR SWING

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**ABSTRACT**

The aim of this project was to design and prototype a vestibular swing for use by autistic children at Wyman Elementary School, Rolla, MO. A swinging or spinning motion calms an autistic child when his/her anxiety is high. The swings available in the market either do not satisfy the requirements of our customers or are very expensive. A design that incorporates both swinging and spinning motions (Vestibular swing) was successfully prototyped in this project.

### BACKGROUND

Many autistic individuals seem to have impairment in one or more of their senses. This impairment can involve the auditory, visual, tactile, taste, vestibular, olfactory (smell), and proprioceptive senses. Sensory integration techniques are often used to treat dysfunctional tactile, vestibular, and proprioceptive senses. Some of the techniques involve swinging a child on a swing in various ways to help normalize the vestibular sense and rubbing different textures on the skin to normalize the tactile sense (1). A vestibular swing can be defined as a swing that swings and spins and helps in calming an autistic child.

Teachers at Wyman Elementary School are responsible for tutoring some children with autistic disabilities. They had a need for a swing that would help calm these children when under states of excitation or distraction. They also required a swing that will fit inside the classroom, be collapsible when not in use and be cost effective. Since the vestibular swings available in the market did not meet the above requirements, it was decided to develop a product that would satisfy the specified criteria. This task was taken up as a team project for the Modern Product Design course at University of Missouri —Rolla. Our customers were the teachers (who outlined the requirements) and the children. Initially, customer requirements were collected from the teachers at Wyman Elementary School and were used as a basis for the design.

### PROBLEM STATEMENT

The objective of this project was to design, manufacture, test and deliver a vestibular swing to the customers, as per their requirements. Some of the requirements were: a swing that spins/ swings, is easy to operate, holds up to a 110 lb child, accommodates a 4-1/2 feet child in the "superman" position, is easy to install, is safe and occupies less space.

### DESIGN

Several modern design theories and fundamentals were applied to the design of the vestibular swing to help develop an efficient design which best satisfies the expectations of our customers. The design process for the vestibular swing consisted of the following steps: customer needs identification, functional model development, concept generation, concept selection, detail design and analysis, and development of proof of concept test. These and other methods like tuning parameter design, robust design etc. provided a rigorous basis for developing concepts conforming to customer needs, to select the best one and analyze its viability (2).

A total of ten different concepts were generated for the swing. These included swings attached to the ceiling, walls or ground. Rocking motions were also taken to substitute for swinging or spinning motions. These concepts were then fed through concept selection methods called the Pugh chart and the Decision matrix to help select the best model given the set of customer specified criteria. A collapsible A frame unit, standing on the ground, with both swing and spin motions derived from an overhead frame, was selected over other concepts.

Once this was done, mathematical models were constructed to determine certain design parameters and to test the viability of the design by doing static and dynamic analyses. Working Model¤ was also used to do kinematic analysis. An 8in:5ft scale model for the selected design was made from wood to test whether it satisfies basic customer requirements of swing and spin. The results validated the design and the design was cleared for final prototyping.

This design satisfies customer requirements better than the other models considered because of the following advantages: easy operation and installation, can be collapsed quickly by removing two bolts, A frames for the sides provide stability, a locking mechanism provided at the overhead bearing easily isolates the swinging and spinning motions, and the design conforms to the customer specified requirement of simplicity.

## DEVELOPMENT

An A frame swing design that is collapsible and that also incorporates the spin motion was developed. Collapsibility conserves the space when the swing is not in use, which is an innovation to the existing designs available in the market. Spin motion, an innovation in the swing also satisfies the customer need.

Square steel tubing was used for the framework of the swing. Steel base plates for supporting the side frames were used as foot plates. Eyebolts and D-clips were used to attach the swing to the swing frame. A turntable bearing was selected for the spin motion. 4-ply plywood was used for the platform of the swing. Hinges ensured that the swing was collapsible. Grade 8 Bolts, Nuts and Washers were used for assembly. 1/2 inch nylon rope was used to suspend the platform swing. The component dimensions were: two steel square tubing back legs of height 80.65 inches and two steel square tubing front legs of height 81.65 inches, two square base plates of width 12 inches, two bearing mounting plates, 5x7 inches, and four square foot plate flanges of width 4 inches. Grinding, drilling, welding and cutting operations were performed to manufacture the product. The vestibular swing was cycle tested using varying loads above the maximum requirement.

The entire cost of the swing came out to be $400 dollars, which does not include the labor cost and the manufacturing costs. Our product s total cost will be in the range of $1200 - $1300. This would still be considerably lower than the ones available in the market, which costs around $2400 (only for the frame), thus making our product very cost effective.

## CONCLUSIONS

After testing, the swing performance proved to be satisfactory. The vestibular swing was completely assembled and presented to Wyman Elementary School on December 20th 2000. The advantages of our design are simplicity, collapsibility when not in use, and the safety of the product.

Swing has been in use for the last four months and its operation has been smooth and noiseless. The teachers at Wyman Elementary are satisfied with the performance of the swing. The children enjoy using the swing.

Figure 1: Vestibular Swing at Wyman Elementary

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## ACKNOWLEDGMENTS

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# Voice-Activated Remote Control

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## ABSTRACT

A voice-activated remote control has been developed to assist an adult who has limited use of his hands. This controller allows the user to control the functions of TV, Cable and VCR entertainment system by using voice command. This hand free controller device allows disables with limitation of using their hands to be able to control their entertainment system simply by speaking.

## BACKGROUND

The voice-activated remote control device is mainly based on the use of voice recognition technology. Voice recognition technology has grown dramatically over the last decade. The accuracy and the response time of voice recognition processors have been greatly improved. Therefore, voice recognition technologies have become more popular and widely use in our society. Especially, the use of voice recognition technology has been helping people with disabilities to be able to control devices and appliances with voice commands.

In October of 2000, Derryl has been referred to me as my client of the Assistive Technology at the University of Massachusetts Lowell. Derryl is a disable who has no control of his arms and legs. He can speak and able to control his head movement very well. He spends most of the time on wheelchair or on his bed. Due to his disabilities, he is unable to control the entertainment system in his bedroom. He could not change the channel or volume of the TV and unable to use the VCR. He needs to rely on other house members to help him to do so. This had caused a lot of inconvenience for him.

## STATEMENT OF PROBLEM

The objective of this project was to design a voice-activated remote control that could be used to control the TV, cable box, and VCR entertainment system.

## RATIONALE

The first phase of this project was to understand what kind of entertainment system the client would want to control such as the TV, cable box and the VCR in his bedroom. I also discussed with him about what kind of functions he would like to control over his entertainment system as a list of requirements that to be controlled by voice commands. It was decided that the voice-activated remote control would be able to do the same function controls as the regular remote controller of the TV, cable box and VCR.

After specification and requirements were decided, I began to do research and development. Throughout the development, I have scheduled meeting with my client to discuss about the project's progress.

## DESIGN

In the voice-activated remote control design, it basically consists of three parts: a voice recognition system, a universal remote controller, and a logic circuit which connects the two. The voice recognition processor used in this project was the Voice Direct™ 364 from Sensory Inc. Voice Direct™ 364 is a speaker-dependent speech recognition module, allowing training of up to 15 words with duration of 2.5 sec each. Using sophisticated speech recognition technology, Voice Direct™ 364 maps spoken commands to system control functions. Each time one of the words is recognized, output pins on the module are toggled high for 1 second. With proper use, greater than 90% accuracy can be achieved. A logical circuit will decode the outputs of the processor. Then the logical circuit will assign which function of the universal remote should be on.

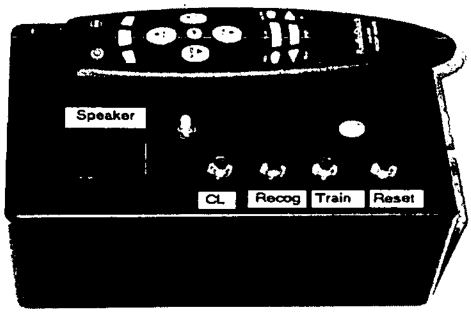
The second part of the design is the universal remote controller. I have decided to use a single 3 in 1 universal remote to control the TV, cable box and VCR. Therefore, the universal remote was modified inorder to be controlled by the logical circuit. Inside the universal remote there is an infrared signal processor sends out infrared signal to control appliances. The infrared signal processor packaged in a 28 pins IC chip. With correct pin-to-pin connection, an infrared signal correspond to those pins connections will be sent out for controlling appliances. For example, if pin 1 and pin 11 of the processor are connected together, an infrared signal for POWER ON will be send to the TV.

The third part of the design is the logic circuit. The purpose of the logic circuit is to control the pin-to-pin connections of the infrared signal processor corresponds to the output module of the voice recognition processor. This logic circuit consists of combination sets of logical gates to do the decoding and switches to do the pin-to-pin connections. Reed relays were used to act as switches to do the pin-to-pin connections. Reed relays serve in many applications requiring low and stable contact resistance, low capacitance, high insulation resistance, long life and small size. In this project, when a reed relay receives an active high signal from the logic circuit it will connect two assigned pins of the infrared signal processor together. Once the pins are connected, the appropriate infrared signal will be sent out from the remote.

## DEVELOPMENT

The voice-activated remote control device basically consists of two parts. A universal remote and a 8x5x4 inches box containing the voice recognition processor and the logic circuit. A picture of the complete unit is shown in Figure 1. The universal remote control was modified to have its control wires extended through its plastic cover into the box. Therefore, the logic circuit and the relays in the box will be able to communicate with the infrared signal processor in the remote. There are several buttons located on the top of the box for words training purposes. There is also a speaker located inside the box. The purpose of the speaker is to use speech prompting to report memory status, provide training instruction and notify user when there is an error occur. A microphone is placed on top of the box for the voice recognition processor to recognize voice commands. The unit is design to be powered by 4 AAA batteries or a 5 Volt DC adapter.

Figure 1 – Voice-Activated Remote Control Unit




## EVALUATION/DISCUSSION

The voice-activated remote is easy to use and user friendly with speech prompting technology. The unit is small size, portable and affordable. The entire unit including the remote is cost about $120 to make. The cost is must less than other voice-activated remote control which must be connect to a computer. The computer will increase the cost dramatically with hundreds of dollars. One feature of this unit is that the universal remote is detachable from the control box. When the remote is detached, it can be used as a regular remote controller, which is very convenience.

To start using the unit, first, user needs to train the Continuous Listening (CL) word by pressing the <u>CL</u> Button. This CL word is the word user must say before saying the second stand-alone word for accessing the 15 processor voice recognition memories. After the CL word was successfully trained, user is required to train the other 15 voice recognition memories by pressing the <u>Train</u> button for training each one. Each word represents one of the 15 functions of the remote. The order of word training for all 15 remote function is fully explained in the user manual. For example, user must train word one memory to represent the POWER function of the remote control and train word two memory to represent the VCR Mode function of the remote control and so on, up to word fifteen. If user made a mistake during training, user can press down both the <u>Recog</u> and <u>Train</u> buttons for 1sec to clear all memories and start the training over again.

Once the unit is trained, user can press the <u>Reset</u> button once and start using the unit. When user want to use the remote, user first speaks the CL word to the micro-phone and look at the green light carefully. Once the unit recognizes the CL word, the green light will blink once. Right after the green light blinked (about 1 sec or so), user should say one of the stand-alone words which was trained into the 15 memories during training. When the voice recognition processor recognizes the voice command, the box will control the remote to send out the correct signal that corresponds to the voice command.

## ACKNOWLEGEMENTS

This project was supported and funded by the Assistive Technology Program and the Research Foundation of University of Massachusetts Lowell. I also want to thank Professor Donn Clark and Mr. Alan Rux of the Assistive Technology Program for giving me supports and advises on completing this project.

# VOICE ACTIVATED RADIO CONTROL TRUCK

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## ABSTRACT

As technology is becoming more advanced, so is voice recognition. Our society has become more adapted to speech the recognition system available today. This technology has not been used to its fullest capacity in one area. That is among the handicap, especially children who are unable to make full use of their hand movement. Voice activated radio control cars or trucks will give these kids a sense of pride enjoyment in their life. They too can play with a toy that is adaptable to their needs, in a way that is similar to thousand of able body children, who are able to make use of standard radio control toys.

## BACKGROUND

Most of us do enjoy playing with our toys, especially children. As the technology is becoming more advanced, the toy manufactures have marketed more sophisticated toys. Yet, many of these toys manufacturers target their market to only able body people. Many of these toys make it difficult or impossible for children who have limited use of their hands to play with them. When witnessing the children at one of the local rehabilitation center, I saw these kids playing with their toys. They seemed so limited as to what they can play with. This inspires me to think of, I could do something about this. Originally, I was going to modify a doll that required to be squeeze to activate certain tasks. Later our group uses this idea of voice activated toy car as a product for our company in capstone proposal class. Then Professor Clark ask us pursue this idea and bring it to reality.

## PROBLEM

Children and adults alike love to play with their radio control cars or trucks. However, those with limited or no use of their hands may find it impossible to do so. There is no availability of voice activated radio control toy vehicles on the market today. These people are deprived much of the joy that come with playing with such a toy, while the able body people take for granted.

## DESIGN

The speech recognition technologies are become more advanced, but are not yet perfect. There are all kinds of radio control toy vehicles in the market today. Designing an interface circuit to work with speech recognition and radio control circuitry is something that can be easily done. Speech recognition used was HM2007 kit from the Images Company for $100. Its capability of recognized up to 40 words, each word with a maximum length of .92 seconds. The recognition accuracy can be achieved at 95% or greater. The drawback to this chip is a speaker dependent. There is only six basic commands needed to control this voice activated radio control truck. These commands are forward, reverse, stop, left, right and straight. These commands can be utilized by allocated four words space or location for each command. Therefore, users can train in all four locations for greater percentage of recognition accuracy. This system can also be shared by four different users; each person can train at one location. The interface circuit was achieved by using basic logic design. This is done by process output signals, from speech recognition circuitry to controlled four movement in the radio control unit. The radio control truck used for this project is a 1/14 scale Dodge Ram Truck by New Bright Industries, and it was purchased for $34.99.

## DE VELOPMENT

The first step of this design was to determine what kind of signal was required to control the forward, reverse, left and right movement in a radio control unit. It was determined that this controller forces the forward (reverse as well as left and right) contact to ground in order to move the truck. There is no variable speed to this, once the contact is made the truck starts to move right away.

The next step is to determine how the speech recognition circuitry worked, what kind of output signals does it give? The output signal for speech recognition is decimal code in a binary format, data D0 to D7. For example, when activate a counter of 01, data D0 would go from low to high (see table 1). The output signal is logic high, and the input signal that required for controlling the truck's four basic moments has to be ground. A transistor was selected to control each of the four outputs signal, as to convert the logic high output to ground (see figure 1).

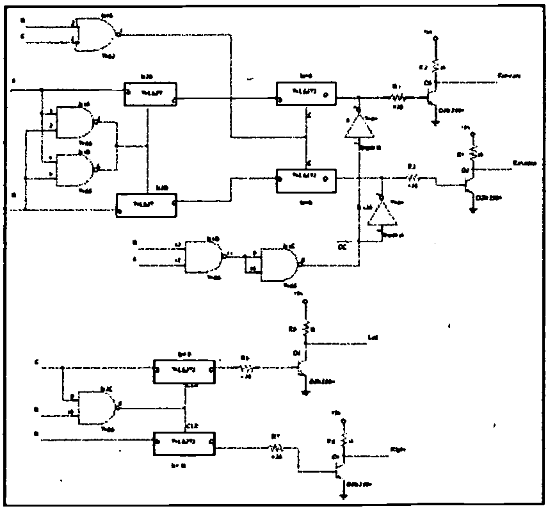
The interface circuit consists of six IC, eight resistors and four transistor. There are two sections to this circuit, forward, reverse and stop are divided into one section and the other section is left, right and straight. U1A and B (74LS00) and U3 (74LS273) were used to ensure that forward and reverse would not activate at the same time. U4 (74LS373) is an Octal D-type Transparent Latches, this is serve as to holds the output signal at logic high while the left or right command is activated. In addition, when U1C and D go high (stop command) then output buffer of U4 would clear all signals. In the second section of the circuit left, right and straight is controlled by U5A (74LS00) and U6A (74LS273). When U5A is turned on, U6A will be clear, and in turn, it will clear either left or right. The clock (CLK) is taken from a 3.58 MHz Crystal Oscillator that connects to pin 2 and 3 of the HM2007. Pin 2 is the output; this pin is connected to pin 11 of 74LS273. Both circuits shared a single 9VDC battery. The 7805 voltage regulator was used to obtain +5 VDC. Also, there is a 3.5 VDC lithium battery uses for retained memory for the static RAM. This battery should last for a long time, since the power consumption here is very small.

The Dodge Ram truck speed as discovered to be too fast for children to play with, especially the handicap. In order for a child to use it, the truck's speed needs to have the ability to be adjustable. This was accomplished by adding 10Ω, 3 watts potentiometer in series with one of the motor control's line.

**Table 1: Output Signal Speech Recognition Circuit**

| Output from Connector 6 (D0 to D7) | | | | | | | | Display |
|---|---|---|---|---|---|---|---|---|
| D(8) | C(4) | B(2) | A(1) | D(8) | C(4) | B(2) | A(1) | Count |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 01 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 02 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 03 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 04 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 05 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 06 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 07 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 08 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 09 |

**Figure 1: Interface Circuit**



## EVALUATION

This truck is equipped with variable speed control. The truck performs well at low speed and it easy to maneuvers even in confined areas. At high speed, a larger area is required to operate. Because the truck is considerably fast. This is only a prototype system; it is not yet perfect, there are some work is needed. For example, error code 55 (word to long), this causes truck to turn left and sometime forward. This is due to the sharing of same data busses as forward and left commands.

The microphone is an essential part of the voice recognition systems. Therefore, a good microphone is needed. The microphone that came with HM2007 kit, the cable founded to be too short. In addition, cable was mounted right to the PCB. This required a user to bend down as to give a command. A longer microphone cable is necessary in for the user's mobility. A standard over the head PC microphone was selected over the tie clip type. This type of microphone gives a better percentage of recognition accuracy, because the distance between the mount piece and the speaker is close and constant. The microphone used came with 8-ft cord, 1/8" (3.5 mm) plug and frequency range of 100 to 16,000 Hz. Impedance of 32Ω, and sensitivity of -56 dB +/- 3dB, V/μbar@1kHz.

## DISCUSSION

This project demonstrates that voice activation can be added to any radio control toy vehicle in the market today. We have the technology as this project shows, to accomplish this task at reasonable price. The parts for this prototype radio control truck cost about $200.00. If this were to put in mass production, the price should drop significantly.

## REFERENCE

1. SAMSUNG Logic Families Data Book 1986

## ACKNOWLEDGMENTS

This project was supported by university of Massachusetts, Lowell. Capstone Project supported by Professor Donn Clark and Alan Rux. Thank to John O'Fallen, Bob Hanlon, Hai Lui, Art Reed, and Paul Brockman in helping with the project. In addition, thank to my wife who had been helping me with my grammar.

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VOICE CONTROLLED TOY CAR

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## ABSTRACT

The need for technology to assist people with disabilities has rarely been disputed. In many areas, our society has become more aware and accommodating to those with different needs, but little attention has been placed on enhancing the ability of the disabled to enjoy the nonessentials of life, such as playing with toys. A voice-controlled toy, such as a radio controlled car, can give a children with limited hand use a degree of freedom and independence in their play that they may have yet to experience. With new advances in technology, the cost of modification, after research and development, is now under $100.00. This makes speech controlled toys a viable option for disabled children.

## BACKGROUND

The explosion of technology has permeated seemingly every aspect of our lives; children's toys have been no exception. Many toys, such as the Furby, contain various sensors, detectors, output devices and even microcomputers. Nevertheless, even as the deluge of technology continues to flow, the application of this new technology has yet to be as thoroughly applied to toys for use by disabled children. Parents of a disabled child, depending on the child's abilities, may have limited choices for suitable toys for their children although the technology exists to create toys for children with many differing abilities. This reality is the reason for building a voice controlled toy car. Children, and adults, who have limited or no use of their hands, can use this car giving them the freedom to play with a toy.

## PROBLEM

Children with limited or no use of their hands may find most, if not all, of the available toys difficult to impossible to use. These children are deprived of much of the play that able-bodied children take for granted. They may be limited to passive activities, such as watching TV, or activities that are more involved only when assisted by a caretaker. Speech activated radio controlled toys would allow the child a new degree of freedom and independence. Once the toy was activated, the child would be able to control the toy with out the intervention of the caretaker.

## DESIGN

The most efficient way to create the car would be to use an existing radio controlled car, an existing stand-alone speech recognition device, and unite the two units with an interface circuit. The r/c car could be any presently on the market, but the best choice would be a slower car with only the basic commands: forward, backward left and right. The cars that are very fast or do specialized tricks may be too fast or complicated for voice control. The car chosen, A Nikko 'Road Hog' met these constraints but was slowed down further to allow time for the vocal commands to be processed. The speech recognition unit must be accurate, easy to use and low cost. The unit chosen, a Sensory Inc. VD364 boasts 99% accuracy, user-friendly voice prompts and a cost of $50.00. The interface between the two units must be reliable, cheap and flexible. The best choice seemed to be a microprocessor combined with an op-amp. The microprocessor, which can be found for under $5.00 provides a cheap and flexible interface when combined with an op-amp to drive the transmitter circuitry.

Along with the basic directional controls found on traditionally controlled r/c cars, some special features may be beneficial to special needs users. Already implemented are half speed, slalom, and figure eight features with room for five more. All these commands can be activated and deactivated by a single vocal command. This eliminated the number of commands that need to be spoken. For example, the slalom command alternates left and right until cancelled which eliminates the repeated vocalization of left and right.

## DEVELOPMENT

The voice-controlled car was conceived for a class project, but after some research it was determined that this was a viable task for a senior electrical engineering final project. The initial concept was simple buy an off the shelf r/c car, a stand-alone speech recognition unit, and combine the two using a microprocessor.

The first step consisted of researching the available speech recognition units (SRU), cars and microprocessors. After much Internet research the Images Co. HM2007 was chosen as the SRU, and the Scenix SX28 as the microprocessor. As limited information of the internal workings of the specific r/c cars is available, a low priced basic functionality car was purchased off the shelf. The remote control of the car turned out to be perfectly suited for modification. Each of the four directional controls, forward, backward, left, and right, could be activated be applying +9V to one of four jumpers on the circuit board.

Next, the internal workings of each component were determined. After training the SRU with the appropriate commands, the SRU would output the appropriate two digit BCD corresponding to one of 40 memory locations upon recognizing a spoken word. A small program was written for the microprocessor, which would interpret the BCD output of the SRU and set the appropriate combination of the four output pins. Each one of these pins fed into an op-amp, which boosted the +5V output of the processor to the +9V needed by the remote control transmitter.

This conglomeration of circuit boards was connected together, using a plethora of jumper wires, on a sheet of Styrofoam. The car worked well except for the chosen SRU, which had problems with accuracy. At different times the SRU would recognize nearly every word while at other times seemed to miss nearly every word, therefore a replacement needed to be found. The Sensory Inc.VD364, the replacement SRU, performed much better with an estimated 95% correct recognition. This accuracy came at the price of slower response, about one second between commands. As the time to traverse a room at full speed was less than one second, the car collided with objects when used indoors.

To improve the controllability of the car with the increased response time, the car was slowed down by adding an "slow down" vocal command. By using the microprocessor to quickly turn the forward or backward output signal on and off, the car would move at a slower, though jerkier rate. When using this command when in a confined area the car becomes much easier to control.

After the circuit was constructed, and software written, the unit was packaged into a battery powered hand held unit. The final unit came equipped with power management features, and a head worn microphone. This unit underwent testing by various people to determine its performance and ease of use.

## EVALUATION

The car performs well when the each user programs his or her own voice templates into the SRU, a process that takes about one minute. After programming and some training each test subject was able to control the car to a fair degree of accuracy. Testing was also done on younger children aged three and four who found the programming process to tedious and difficult and then soon lost interest. The difficulty arose in saying the correct command words at the correct time with a consistent volume and timber.

In confined areas the car requires some training and skill to maneuver with out crashing. When used in open areas, the car performs quite well maneuvering as requested with most every command. The car also responds well when the user relies on a preprogrammed voice template. Though not as accurate as when the user's voice is programmed into the unit, the accuracy was sufficiently high to allow several users to use the car with out reprogramming.

Many areas still need to be addressed before one could consider producing this device beyond the prototype level. This prototype was constructed by hand with point to point wiring, which tends to be less reliable than PC board construction. Background noise and variances in the user's voice can cause the car to ignore a command. Many times the noise generated by the car's motor was loud enough to cause missed commands. In addition, the excitement in a user's voice when confronted with an impending crash would sufficiently change the voice to the point where the car would not respond, and then of course crash.

## DISCUSSION

This prototype voice controlled toy car demonstrates how a toy can be modified to accept spoken commands. After the initial development has been done, the cost of parts per unit is under $100.00, which is not unreasonable, considering the benefits to a disabled child who might use the toy. The use of vocal commands for a toy car or other similar device is still not a viable substitute for manually operated controls when other options exist. But, for those who have no other option speech recognition can give them the ability to control their world in new and exciting ways.

## ACKNOWLEDGEMENTS

The author wishes to acknowledge the support of Professor Donn Clark and Alan Rux who together lead the assistive technology program at the University of Massachusetts at Lowell. Professor Clark first saw the viability of the car and encouraged its development. In addition, thanks to Bob Hanlon who first conceived of a voice controlled toy car, And finally thanks to Visay Siskorage and Hai Lui who are developing a similar car. They provided insight and direction in the development and design as they struggled with their own creations.

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# Augmentative and Alternative Communication (Topic 2)

# EFFECT OF SPEECH RATE ON COMPREHENSION AND ACCEPTABILITY OF SYNTHESIZED NARRATIVE DISCOURSE

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## ABSTRACT

This study investigated the effect of speech rate on listener comprehension and subjective judgments when listening to synthesized narrative stories (MacinTalk Pro). Fifty able-bodied adults individually listened to synthesized stories at five different speech rates between 8.75 to 140 words per minute (wpm). For each story, listeners answered multiple-choice comprehension questions and rated their subjective judgments about the communication competence of the speaker. Analyses revealed significant differences related to speech rate for both comprehension performance and subjective judgments. Seventy words per minute emerged as an optimal rate for narrative discourse comprehension, with increases in speech rate resulting in more favorable ratings of communication competence.

## BACKGROUND

The slowness of communication speed in augmented communication can be summarized as a "Rate Problem" to be improved for better communication of individuals using Augmentative and Alternative Communication (AAC) systems. The average AAC communication rate is usually less than 10 wpm (1), resulting in speech rates more than 10 times slower than natural speakers. This slow rate imposes several significant barriers on speaking partners' ability to perceive and comprehend utterances produced by augmented speakers in interactive contexts (2, 3, & 4).

Despite technological improvements in the AAC field, communication device constraints and/or communication limitations still prevent augmented speakers from engaging in and sustaining real-time interactions. Although the rate effect of synthetic speech on listener comprehension and acceptability has been recognized as one of the top three research topics to be investigated for successful use of AAC devices, the practical rate effect of synthetic speech still has not been adequately documented.

## RESEARCH QUESTION

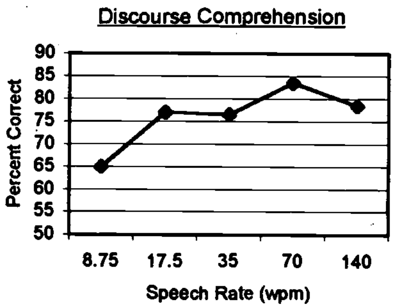
The purpose of this study was to investigate the impact of speech rate on synthesized narrative comprehension and subjective judgments of listeners. Research questions included:

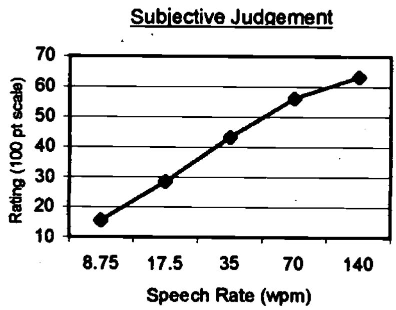
- What is the relationship between speech rate and comprehension performance?
- What is the relationship between speech rate and subjective judgments?

## METHOD

Fifty able-bodied individuals participated in this study as listeners. The listeners were individually tested over a two-and-half-hour period, listening to five stories at five different speech rates that were randomly assigned from a pool of 10 narratives (5). After listening to each story, listeners answered multiple-choice comprehension questions, then answered 10 subjective judgment questions of a competence evaluation questionnaire (100-point scale). All stimulus materials for experimental conditions were randomly assigned to participants using a partial Latin Square design.. All narrative stimuli, comprehension questions and the communicative competence rating scale were presented via the computer. Speech rate served as independent, within subject variable. Dependent measures included percent of correct responses for comprehension questions and subjective judgments rating scores. To meet the criteria for normality and equal variance assumptions, all data were transformed using the arcsine transformation method (6). A repeated measures ANOVA was employed and pairwise comparisons were made using the Tukey HSD and individual t-tests. The level of significance was set at $p < .05$.

## RESULTS




Figures 1a & 1b: Discourse Comprehension and Subjective Judgement across Five Speech Rates.

Listener comprehension performance across speech rates displayed a curvilinear trend with significant linear, quadratic and 4$^{th}$ order components. Comprehension performance increased significantly between 8.75 and 17.5 wpm, was stable between 17.5 and 35 wpm, then, improved significantly at 70 wpm. Finally, comprehension performance declined significantly between 70 and 140 wpm.

Analysis of listener's subjective judgments revealed significant linear and quadratic trend components across speech rates. As shown in Figure 1b, listeners rated their experiences more positively as speech rate increased, accompanied by a slight downward deflection between 70 and 140 wpm. All between-rate comparisons were statistically significant.

## DISCUSSION

The results of this study indicate that faster speech rates have a significant positive effect on both listener discourse comprehension and subjective judgments of communication competence at least up through 70 words per minute. At the slowest speed (8.75 wpm), both comprehension and subjective judgement were at their lowest point – an important finding, given that the average reported communication speeds approximate this communication rate (1, 2, 7, & 8).

Improvement in comprehension and subjective judgments with faster speech rates is also in line with recent findings by Todman (4) showing systematic improvements communication competence ratings as a function of faster communication speed. Interestingly, the optimal listener comprehension rate of 70 wpm is asupported by previous research findings from our lab indicating comprehension processing problems associated with synthetic speech played at normal speech rates (7, & 9). Unlike comprehension performance, subjective judgment scores systematically increased with speech rate. Perhaps this measure is a more sensitive indicator to changes in speech rate than the comprehension task, or taps other communication related dimensions not addressed by the comprehension measure. Finally, these results provide clear - although limited - empirical evidence that faster AAC technologies can substantially improve listener comprehension and their communication competence perceptions of the device user. Using these data as an initial benchmark, we encourage the manufacturing community to research and develop technologies to provide AAC speakers with the means to achieve and sustain communication speeds from 20 words per minute upwards to approximately 70 words per minute. Additional research needs to be conducted to more precisely specify these speeds and associated task demands.

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# A COMMUNICATION "TOOLS" MODEL FOR AAC INTERVENTION WITH EARLY COMMUNICATORS

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ABSTRACT: This paper presents a conceptual model of communication for young children based on the numbers and types of communicative tools that they use for conveying messages. These tools include both tangible and intangible aspects of communication, including the use of behavior, language, messages, symbols, and other people for communication. Particular aspects of the model represent tools used by non-speaking children who rely on AAC. A brief overview discusses the roles of tools in communication for speaking and non-speaking children, including the roles that adults play in providing certain tools themselves to scaffold children's early communication. Implications for AAC intervention and assessment are included.

## BACKGROUND

Typically developing children's control of early linguistic experiences within interactions tends to rely upon on nonverbal behavior tools that facilitate later linguistic development. For instance, referential gestures, such as "gestural labels", tend to be produced first in routine contexts with joint attention to an object, and gradually become symbolic means of referring to that object out of context (1, 2). Children with severe motor and communicative impairments have restricted opportunities for controlling communication tools through gesture or other referential movements. For instance, a child with poor hand/arm control will have more difficulty learning to give items to request actions in the conventional manner displayed by children without disabilities. Children with severe physical impairments tend to be at risk for language delays resulting from limited opportunity for productive language expression, poor modeling of successful communication using alternative communication modes, and poor adaptation of the communicative environment to unique characteristics of non-spoken communication strategies (3).

If children with physical and/or cognitive impairments are at risk for poor spoken language development, we need to explore alternative early strategies. An augmentative and alternative communication (AAC) system is "an integrated group of components, including the symbols, aids, strategies, and techniques used by individuals to enhance communication" (4). While some intervention emphasizes the symbols and technologies, early AAC intervention also addresses gestures and partner strategies that support presymbolic communication. Communicative expectations for typically developing children are based on extensive research and published developmental milestones. Such developmental milestones are not available for children with severe communicative, physical, and/or sensory impairments (5). Also, if a child's communicative performance is limited, we cannot simply use children's responses or lack of them to estimate children's communicative competence and plan an appropriate set of accessible communicative strategies. This article applies a developmental model of communicative tools based on principles of typical and disordered spoken language development to communication by non-speaking children who rely on technology for communication.

OBJECTIVE: The communication "tools" model has been developed to represent the potential sources of cognitive difficulty in controlling augmented communication for young non-speaking children, in order to plan AAC intervention to improve children's effective communication tools "one hard thing at a time". Specific questions include: a) How do we estimate or change relative difficulty of a communicative strategy for a non-speaking child? b) How do we predict and facilitate next steps in the development of a communication strategy for a child relying on AAC?

APPROACH

Given the difficulty of estimating the communicative complexity of various AAC strategies, intervention in young children's AAC systems often jumps from simple to complex without a thorough understanding of the relationships among different communicative strategies or relative sources of difficulty between strategies. For instance, a frequent goal for a prelinguistic non-speaking child is to learn the cause/effect relationship between hitting an electronic switch and hearing a voice output message or seeing a toy respond to the switch activation. Once the child successfully hits such as switch, a frequent follow-up goal might be to use the voice output switch to convey a spoken message to a listener to request an action. While the physical behaviors and external tools are roughly equivalent for these two types of activities, the underlying cognitive and communicative complexity is considerably different. The following table outlines a model of communicative tools for non-speaking children.

| Table 1: Type of Communicative Tool | Example |
|---|---|
| Child initiates a behavior | Reaches own arm out and controls its movement |
| + Toy or other direct object | Pushes switch with arm movement |
| + Message Content | Child enjoys and wants to continue tickle game |
| + Symbolic representation | Chooses picture symbol representing "tickle" |
| + External Device | Controls a nonbehavioral means of communication |
| + Language | Conveys specific semantic content: More tickle |
| + Voice Output | Hears "more tickle" from device |
| + Affects other person's behavior | Partner attends to and interacts with child |
| + Communicative Outcome | Child anticipates/reacts to specific tickle activity |

The first tool that children must control is their own body (a one-tool system), including eyegaze, sound, or movement. Most early tools aren't physical objects but separate aspects of interaction (e.g. a message is a type of tool). Children may have a repertoire of signals that they produce consistently that familiar partners recognize, even if those signals are not produced with the intent to communicate to a partner. Other communicative tools can be added to the child's behavior to form communicative signals of two or more tools. For instance, a child might smile (own behavior) to directly elicit a social response from an adult (adult behavior), for a two-tool system. Similar two-tool systems may combine the child's behavior with a toy (e.g. shaking a rattle) or with a communicative message (e.g. vocalizing a distinct protest sound). Tools that speaking children may add in more complex messages include anticipation of a specific response, language, and spoken word output. Additional tools common to early AAC include a symbolic representation (such as a representative picture symbol or sign), external device (such as a switch that plays a prerecorded message), and the spoken voice output of such a device. The external device and its voice output message are considered separate tools, since children can interact with the physical device without attending to the voice output produced. Also, the task of deciding to communicate using an external device not part of one's body is presumed to add metacognitive load to the communication task above that presented by the voice output of the message alone.

In Table 1, nine tools intervene between the child and the desired outcome, although fewer tools may be used in supported play. For instance, children could anticipate the tickle response by hitting the switch without understanding the language/symbolic content or the function of the switch as a specific communicative mode (Behavior + Object + Message + Voice Output + Other Person + Anticipation of Outcome = 6 tools). More simply, a child who enjoys hitting switches as a two-tool system (Behavior + Object) might be exposed the voice output interaction in order to prompt a three- or four-tool communication event (Behavior + Object +/or [Message] +/or [Anticipate outcome]). At first, the partner provides the message (tickle) for the child with contingent feedback for their behavior, to prompt the child to convey or anticipate the tickle message independently.

DISCUSSION:

Assessment: Comparing the relative difficulty of a communication strategy. If a communication task is too difficult for a child, partners can try reducing or scaffolding the number of tools that are necessary to accomplish particular communicative goals. Reducing complexity of a communication situation often involves partners supporting more of the "tools" necessary for a child to be successful. For instance, pushing a voice output switch to hear a familiar voice is usually a two-tool system (behavior + object). However, using the same switch to request "more juice" is actually a very complex behavior, involving: Child's behavior + Object + Other person's behavior + Message Content + Language [+ Symbolic representation] + Device. A more realistic next step beyond the first use of the voice output switch might be to add only one additional communicative tool to the two-tool interaction, such as behavior + object + message content (which could still be "more juice"). In order to help the child learn to associate the message content with that activity, the adult would provide the juice immediately contingent upon the child's behavior, and provide direct feedback that the switch output control resulted in the juice being offered. The responsibility for managing the language, other person's behavior, and communicative nature of the device would be provided by the partner, to scaffold the child's behavior into a more complex communicative act with support. The extent to which a child can successfully control a multi-tool signal within a given situation can depend upon the child's state and relationship to the desired result. The more complicated or frustrating the task, the simpler the child's communicative signal needs to be. For instance, when a child is upset, he/she is more likely to use a simple behavior that adults respond to immediately (such as fussing) than a complex behavior at their threshold of "tools". In a highly familiar and predictable context, such as a feeding routine, a child is more likely to be able to incorporate multiple tools and challenge their current communicative skills.

Intervention: Goal development based on communicative tools. Intervention based on a tools model focuses on two types of goals: expanding children's potential combinations of tools at their current level of complexity, and increasing their number of communicative tools for familiar contexts and activities. Expanding a child's current variety of tool combinations involves prompting new communicative situations in which a child's signals can control an event without adding more combined tools than seen in his/her repertoire of signals. For instance, a child who only produces three tool signals in a few situations (such as behavior + other person + message to request more "Row your Boat") would be prompted to expand three-tool signals into other familiar contexts (such as behavior + toy + message to indicate "turn it on"). As the child builds a repertoire of three-tool signals, additional tools can be added to familiar signals to expand them into four-tool signals. For instance, the adult might prompt the child to look toward the partner before turning on the toy, to prompt adding the "other person" tool to the toy message. For "Row your Boat", a four-tool combination might involve adults modeling a specific gesture or symbol for this song to distinguish it from other preferred songs requested by the child.

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# AAC SELECTION RATE MEASUREMENT: A METHOD FOR CLINICAL USE BASED ON SPELLING

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## ABSTRACT

The rate at which a person who relies on AAC (augmentative and alternative communication) can make choices from an array determines the speed of communication. Automated language activity monitoring (LAM) tools allow the measurement of selection rate based on logged data generated by actual AAC system operators. A method for measuring selection rate based on spelling speed is presented. Implications are significant for clinical assessment and intervention.

## BACKGROUND

The AAC clinical processes initiate with a team commitment to work toward the goal of AAC. The team agrees to provide the supports and services that result in the most effective communication possible for the individual. Generally, effective communication is accomplished through spontaneous novel utterance generation (SNUG). For people who rely on AAC, one measure of communication effectiveness is communication rate, which is almost always far slower than natural speech. Therefore, every effort must be made to maximize communication rate for this population. Communication rate is influenced by many factors. By far the most significant factor can be the language representation method (LRM) employed for accessing core vocabulary. However, the speed of making selections also can be an important factor.

Once the team has determined the LRM(s), decisions regarding the most appropriate selection technique must be made. Research on how different AAC configurations affect speed and efficiency is needed to facilitate the clinical decision-making process for motor access (1). For most teams, determination of selection techniques (e.g., keyboard vs. headpointing) has been qualitative ratings of speed and reliability. Decisions relative to selection rate have been based on clinical intuition, trial-and-error counts, or not documented.

Recent work has resulted in AAC language activity monitoring (LAM) (2, 3) for clinical use, funded in part by the National Institute for Deafness and Other Communication Disorders on NIH, and a comprehensive universal logfile standard (4). These developments have made available tools to collect language sample quantitative data on which to base assessment and intervention decisions. LAM data is being used to produce quantitative AAC performance summary measures.

A method for measuring selection rate proposed in late 1999 has been used clinically (5) since that time. While the results have been useful, the method requires that the subject produce a particular pattern of selections. While this is not onerous, it does require an intentional setup and thus may be done infrequently in the course of normal therapy.

## OBJECTIVE

The objective of this work is to provide a method of extracting selection rate measurement from normal LAM data. Selection rate can be used for the comparison of different selection techniques on systems of different array sizes, the measurement of progress in learning to use a particular technique, and changes in rate that might occur as a result of other short term (e.g., fatigue) or long term (e.g., learning curve, physical improvement or deterioration) factors.

**METHOD**

The human interface information transfer rate has historically been measured in terms of bits per second. (The rate for able-bodied people is generally considered to be under 100 bits per second. (6)). Consistent with historical measures, for this work the selection rate also is being reported in terms of bits per second.

The size of the array (A) (e.g., number of keys on a keyboard) from which choices are being made determines the number of bits (N) that are available with each choice. $A = 2^N$. $N = \ln(A) / \ln(2)$. The integer number of bits (N) for various array sizes (A) is presented in this chart:

| A | N |
|---|---|
| 128 | 7 |
| 64 | 6 |
| 32 | 5 |
| 16 | 4 |
| 8 | 3 |

Thus, if a person were able to make one choice per second from a keyboard with 128 keys, the selection rate would be seven bits per second. It is important to make the distinction here that the selection rate is not the same as the AAC communication rate. While the selection rate influences the communication rate, other factors, such as the language representation methods employed, do as well.

Language samples from LAM are reported in the following format: **20:37:00 "content"**. The time stamp is a 24 hour format with one second resolution. A space and two quotation marks follow the time stamp. The content of the language event being recorded is between the quotation marks. Each event is presented on a new line.

The original selection rate measurement required the subject to enter a series of specific selections. The LAM would time stamp and record these selections. For individuals who spell as a normal part of their communication, and the letters are selected with a predictable number of selections (generally one), spelled word LAM data can be used to determine selection rate.

The timestamp of the event of the first letter(s) of the word is the start time (S). The time stamp of the last letter (or SPACE) of the word is the end time (E). The selection rate (SR) in bits per second is defined as follows, where L is the number of letters (including SPACE) following the first event selected during the spelling process, A is the number of locations in the selection array used for normal communication, and NS is the number of selections required per letter. $SR = NS\ ((L) \times \ln(A) / \ln(2)) / (E - S)$. For example, if the LAM data showed that a word of eight letters (L = 8) following the first event was spelled (from an array (A) of 128 keys) with direct access to the letters (NS = 1), the first event was at 09:37:17 (S), and the last letter was selected at 09:37:27 (E), then the selection rate would be 5.6 bits per second.

The above process is applied to all spelled single words with no multiple or repeated letters and no error correction in the language sample. Considering that spelling may be interrupted or erratic, the reported selection rate is the weighted average (by L) of all calculated selection rates above the mean. The need for multiple calculations makes this potentially much more time consuming than the original method if done manually. However, as a feature in an automatic analysis program it provides routine selection rate measurement with no additional clinical procedure.

## DISCUSSION

AAC professionals, in order to increase the selection rate, generally will want to maximize the number of keys available to the user. However, range of motion and pointing skill put limits on what can be done in this area. Fitts' Law (7) offers some theoretical predictions on how quickly an individual can make choices of targets of a given size located a given distance from a starting point. Since the application of Fitts' Law in the clinical setting would require information not generally available, the more practical approach is actual trials on keyboards of different sizes.

The development of selection skills requires training time. With quantitative measurement of performance, rational decisions can be made relative to level and stability of performance.

Consideration of error correction is not provided in the above procedure. This is because the number of selections necessary to correct an error is a function of features of the AAC system. The time used in generating errors is included in the test, but no consideration of correction time.

The AAC clinician is cautioned that other factors can influence communication rate. Some of these factors can be far more significant than the typical differences between some selection techniques. For example, motor planning can be important in developing communication speed. Also, an alphabet-based language representation method may produce only a single letter per selection while a whole word per selection may be produced by other methods. And navigating from screen to screen to access single meaning pictures can be problematic and time consuming.

The availability of methods for measuring selection rate has implications in the areas of clinical intervention, outcomes measurement, and research. The end result of the use of these tools is the enhanced communication and higher personal achievement of people who rely on AAC.

By having measurement tools and methods, additional information on the acquisition of personal AAC performance will be forthcoming. Understanding the characteristics of the learning process should impact AAC assessment approaches.

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# A SUMMARY MEASURE CLINICAL REPORT FOR CHARACTERIZING AAC PERFORMANCE

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## ABSTRACT

Augmentative and alternative communication (AAC) evidence-based clinical practice requires quantitative measurement of communication performance. This paper presents a clinically useful report of summary measures based on automated data logging. These summary measures provide the quantitative data necessary for a structured and methodical approach to characterizing AAC performance. Together with traditional qualitative data collection procedures, AAC users and their facilitators will have a standardized report that provides comparable, compatible, and reliable statistical analysis of performance for guiding the therapy process and measuring outcomes.

## BACKGROUND

Clinical evidence characterizing the performance of individual augmented communicators has been limited at best. Few AAC clinicians collect language samples (1). Even when they do, they seldom undertake quantitative analysis that would result in performance data. More frequent clinically, AAC practitioners have relied on traditional qualitative methods to collect evidence and make assessments of outcomes.

Automated logfile data and the clinical tools associated with language activity monitoring (LAM) have provided the field with innovative methods to gather language samples. A set of basic LAM tools, developed in part under a grant from NIH, is available for use with most text-based AAC systems (2) and a comprehensive universal logfile protocol has been defined and is implemented in at least one system (3). Samples collected with these tools can be edited, coded, and analyzed using a variety of automated and manual methods. The result is a set of summary measures that have proven useful in AAC clinical service delivery.

Studies are beginning to appear regarding the performance of augmented communicators using the LAM to collect data. These early studies have looked at the frequency distribution of the various language representation methods used by augmented communicators for spontaneous novel utterance generation (SNUG) (4, 5). One study reported on the use of the LAM with a young child using an AAC device to collect evidence on vocabulary use and early word combinations (6). Current trends with the development of performance monitoring tools and outcomes measurement would indicate continued growth in the reporting of similar studies.

Standardized assessment tools will make it easier to accumulate and compare aggregate outcomes across various parameters (7). A clinical protocol to report summary measures obtained from automated data logging provides a foundation to facilitate application of these tools for clinical decision-making, outcomes measurement, and research.

## OBJECTIVE

The product is a standardized summary measure report based on LAM data. The purpose is to have a systematic, principled approach to reporting summary measures that is comparable, compatible, and has reliable quantitative data for a variety of clinical applications. The LAM report can be used in conjunction with any additional qualitative data or assessment instruments collected clinically.

## METHOD

Operational procedures have been developed for five basic functions needed to generate the reporting protocol. The functions start with the uploading of raw LAM data and, based on the logfile, continue with the editing, coding, analysis, and report generation. Figure 1 represents that process involved in generating a LAM report.

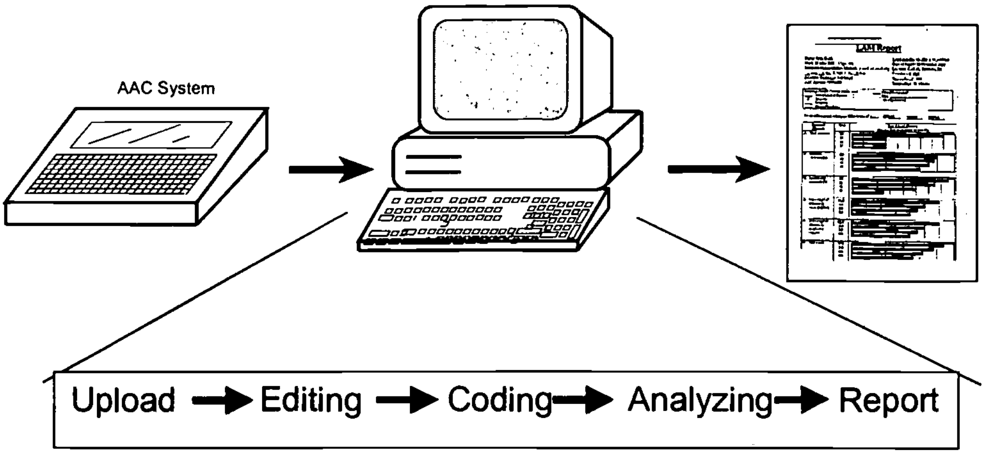



Figure 1: Steps to convert LAM data to a summary measure report.

The LAM report header contains basic personal information on the subject, AAC device and selection technique information, sample date and time information, and the method of language sample generation. Specific summary measures included at this time are: A) Total number of utterances, B) Complete utterances as a percentage of total utterances, C) Spontaneous utterances as a percentage of total utterances, D) Mean Length of Utterance in words (MLUw), E) Mean Length of Utterance in morphemes (MLUm) (A morpheme is an element of meaning. Some words can have multiple morphemes.), F) Total number of words, G) Number of different word roots, H) Average communication rate (words per minute), I) Peak communication rate (words per minute), J) Selection rate (bits per second), K) Language Representation Method analysis, L) Word selection errors per utterance, M) Spelling errors per word spelled.

In addition to the summary measures, appended reports could include the following: 1) Raw LAM data, 2) Edited utterances, 3) Coded utterances, 4) Word list in alphabetical order, 5) Word list in frequency order, 6) Word list by Language Representation Method, 7) Word list comparison to reference lists.

The data is presented numerically and graphically using a bar chart. Up to three historic references are included with the current data to provide easy identification of trends. The summary measure report is a single sheet, both sides. Additional specific reports can be appended to the

LAM Report as considered clinically useful. Figure 2 represents two sections of the report showing performance over time for the frequency of language representation method (LRM) use and word selection errors.

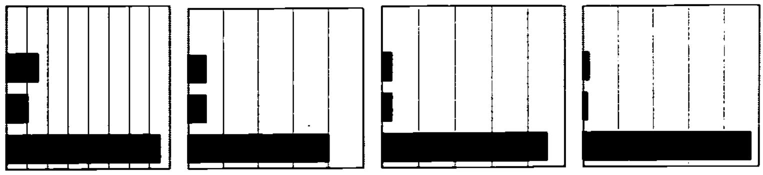
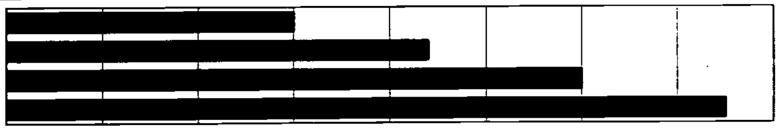
| | | |
|---|---|---|
| Language representation method (LRM) usage for spontaneous utterances (%) | Pic: 0<br>Spe: 3<br>Wpr: 2<br>Sem: 95 |  |
| Word selection errors per utterance | **.30**<br>.44<br>.60<br>.75 |  |

**Figure 2: Typical presentation of data in the LAM Report.**

## DISCUSSION

A standardized report format will help to add structure to the work of the AAC clinician. It also will help to build a common foundation of information and knowledge that will facilitate the accumulation of evidence to support AAC clinical practice.

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# OPERATIONAL PROCEDURES FOR PREPARING LOGFILES FOR COMMUNICATION RATE ANALYSIS

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## ABSTRACT

Automated data logging for AAC has become a reality with the development of performance monitoring tools such as the Language Activity Monitor (LAM). In order to facilitate widespread application of accumulated LAM performance data, procedures need to be documented and disseminated for editing logfiles to increase the usefulness of raw logfile data. One of the most valued clinical summary measures is communication rate, which can be calculated using logfile data either manually or automatically with software. However, reliability of the reported results is based on adherence to operational procedures established for each method of analysis. This paper presents procedures developed to automatically calculate communication rate.

## BACKGROUND

AAC automated language activity monitoring (LAM) provides the field of AAC with tools needed to collect and analyze language samples in a variety of clinically useful contexts (1). The essential function of the LAM is the recording of each language event and the time that it occurs. Hill and Romich (2) as well as Higginbotham (3) have proposed a standard protocol for automated data logging to address compatibility issues and to facilitate the widespread application of actual user-performance data collection. Presently, the LAM function is available as an add-on device or computer monitor for any AAC system with a serial port representation of language events and as an internal function in newer high–end AAC devices. Recorded language samples include content and time stamps. The following is an excerpt of a raw LAM logfile converted to four columns:

| | | | |
|---|---|---|---|
| 16:26:05 "It's " | 16:26:45 "I" | 16:26:49 " " | 16:27:11 "what " |
| 16:26:08 "faster" | 16:26:45 "I" | 16:26:58 "everything " | 16:27:14 "I " |
| 16:26:14 "than " | 16:26:46 "i" | 16:27:02 "out " | 16:27:19 "used " |
| 16:26:41 "sp" | 16:26:47 "n" | 16:27:05 "which " | 16:27:22 "to do " |
| 16:26:42 "e" | 16:26:48 "g" | 16:27:08 "is " | |

This example illustrates that the raw LAM logfile data requires editing to improve the usefulness and value of the time and content information recorded. The editing process is required to prepare the logfile for analysis. Specific procedures are required based on the software application used for analysis and the summary measures selected for reporting. To date, operationalized procedures have been developed for logfiles to be reliably edited for several analysis programs. The software programs are selected based on the summary measures available for analysis that have been proven to be clinically useful. Since communication rate is a summary measure considered highly valued and frequently requested by AAC consumers and practitioners, the focus of this paper is the procedures for editing logfiles for communication rate analysis and setting up Augmentative Communications Quantitative Analysis (ACQUA) program to provide the desired report.

## STATEMENT OF THE PROBLEM

In order to maximize the usefulness of logfile data, procedures need to be developed for editing the logfiles in preparation for analysis. Specific procedures needed to be identified for editing raw LAM logfiles for calculating communication rate using the ACQUA program(4). In order to develop editing procedures, the following problems were identified: 1) the need for a systematic approach for defining and calculating communication rate, and 2) the need to incorporate this definition into any suitable software application, such as ACQUA.

## APPROACH

A standard method for calculating peak and average communication rate in the clinical setting has been proposed by Romich and Hill (5). The method provides a listing of steps to be followed for converting raw LAM data into peak and average words per minute. ACQUA was developed for computing a wide variety of AAC usage statistics based on logfile data. The Romich and Hill method for peak and average communication rate calculation was added to ACQUA version 1.0. Several logfile editing procedures needed to be developed for the program to automatically calculate the same results obtained through manual calculation methods. Since ACQUA does not provide for editing capabilities within the application, editing of the raw logfiles is performed once the data is uploaded into a word processor. The most important editing step involves utterance segmentation and the insertion of an utterance terminator. Frequently, a previously prepared language transcript is used as a model for the utterance segmentation process.

A total of twelve editing rules have been documented for ACQUA to calculate communication rate. The editing process requires the following basic steps. 1) insert utterance terminators at the end of the last word of an utterance, 2) if a terminator exists, move it to the end of the last word of the utterance, 3) take out error words, 4) delete all pre-stored messages.

ACQUA requires the following features be selected to perform the peak and average rate calculations: 1) set Type = Utterances, 2) set Size = Global, 3) set Gap = 1, 4) in tool options select exclude first entry, 5) in tool options check peak value over data windows.

Pilot study data comparing the manual method with ACQUA results indicate that the statistical analyses are consistent using these operational procedures. A prototype LAM report and Communication Rate Worksheet have been designed to record and report the results for clinical application. Tables 1 and 2 are examples of analyzed reported logfile data.

**Table 1: Example of results reported on Communicate Rate Worksheet for picture description task**

| Utterance | Words After 1st Event | Start | End | Time (sec.) | Rate (WPM) |
|---|---|---|---|---|---|
| She is just washing away, not knowing that the water is about to run over. | 14 | 12:26:27 | 12:27:17 | 50 | 16.80 |
| The brother is trying to get a cookie from the jar and it looks like it could fall. | 17 | 12:28:18 | 12:29:22 | 64 | 15.94 |

**Table 2: Communication rates for four augmented communicators' performance during an interview.**

| Subject | AAC System | Selection Technique | Average Rate (WPM) | Peak Rate (WPM) |
|---|---|---|---|---|
| 1 | Unity/Deltatalker | Direct keyboard | 22.01 | 46.67 |
| 2 | Unity/Liberator | Direct keyboard | 18.91 | 35.29 |
| 3 | Custom/Vanguard | Direct keyboard | 16.74 | 20.00 |
| 4 | Unity/Pathfinder | Optical Headpointing | 15.55 | 28.00 |

**DISCUSSION**

Over 40 logfiles under two sampling conditions (picture description and interview) have been edited following the procedures described in this paper. Early inter-rater reliability in utterance segmentation is 96%, and 100% for word-by-word agreement. The use of these editing procedures is a component of the application of tools for measuring AAC performance. Standardized editing procedures provide clinicians with reporting protocols that are comparable, compatible and have reliable quantitative data for a variety of clinical applications. As improvements are made to available tools clinicians will have access to even more time efficient and accurate methods. These tools will increase the application of evidence-based practice using performance measurement based on automated data logging. This in turn will benefit people who rely on AAC through improved clinical intervention service and more consistent, periodic performance reporting.

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# DOMAIN-SPECIFIC WORD PREDICTION FOR AUGMENTATIVE COMMUNICATION

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## ABSTRACT

Many augmentative communication systems employ word prediction to help minimize the number of user actions needed to construct messages. Statistical prediction techniques rely upon a database (model) of word frequencies and inter-word correlations derived from a large text corpus. One potential means to improve prediction is to create a set of models derived from domain-specific corpora, dynamically switching to the model most appropriate for the current conversation. Using telephone transcripts to generate prediction models for 20 different topic domains, we have observed a clear benefit to including domain-specific models in an overall prediction scheme.

## BACKGROUND

Statistical word prediction systems for augmentative communication commonly utilize both word frequencies and inter-word correlations (word contexts). An *ngram* prediction model utilizes the past *n-1* words to predict the *n*th (current) word. Easily derived from large samples of text, ngram models can provide impressive prediction performance – Lesher (1) reports on a trigram (*n*=3) model derived from a 3 million word corpus that yielded keystroke savings in excess of 54%.

There have been numerous techniques suggested for enhancing traditional ngram word prediction, including recency, syntactic analysis, and syntax-based ngrams. One technique that has not been fully explored is the use of domain-specific ngram models – models derived from text samples that are focused on distinct subjects or genres. In theory, these ngram models could be dynamically swapped in and out of use to match the direction of an ongoing conversation.

The text used to train a word prediction system should match as closely as possible the kind of messages produced by the augmented communicator. Although core vocabulary stays fairly constant (2), fringe vocabulary may change substantially through the course of a day as different topics and settings are encountered. The same is likely to hold true for inter-word correlations. We know of no studies that have attempted to quantify the effect of domain shifts on word prediction efficacy. As a precursor to developing a system that can automatically shift between appropriate domain-specific models, we undertook to find the keystroke savings possible in such a system.

Utilizing transcripts from the Switchboard Corpus, a series of 2,400 telephone conversations organized into approximately 60 topic domains (for example, recycling, food/cooking), we have quantified the performance gains associated with utilizing domain-specific ngram models. Although this corpus does not involve augmented communicators, it is conversational, large, and organized into specific topical domains – by far the most suitable large corpus currently available.

## RESEARCH QUESTION

The question we addressed is: Can the use of domain-specific ngram models appreciably enhance word prediction performance in the context of augmentative communication? While our early studies indicated that database domain specificity did not play a significant role in system performance, recent pilot studies indicated that this question merited a more focused investigation.

## METHODS

We chose to study the 20 most frequently occurring topic domains in the Switchboard Corpus. The testing texts for each of these 20 target domains was generated by concatenating all conversations of that domain from the first 12.5% of the corpus. The remainder of the corpus was used to generate the domain-specific training texts. We generated two other training texts: 1) 'Small', consisting of 5% of the training text for each of the 20 target domains, resulting in a text approximately the same size as the average of the 20 domain-specific training texts; and 2) 'Big', comprised of the entire training text. Trigram models were created for each of the 22 training texts.

The experiments were carried out using our IMPACT augmentative communication software. Running in emulation mode, this system can simulate a human using its interface to produce a message. The testing interface consisted of a standard QWERTY keyboard augmented by a dynamic 6-word prediction list. Keystroke savings (KS) were used as the performance measure.

## RESULTS

We measured the performance of four prediction model configurations on each of the 20 domain-specific testing texts. The four configurations were: 1) 'Small' only; 2) 'Auto', meaning that the prediction model was derived from the same domain as the testing text; 3) 'Big' only; and 4) 'Big+Auto', a blending of two ngram models. Figure 1 shows performance on 10 representative domains. Table 1 shows average performance over all 20 domains for the four configurations.

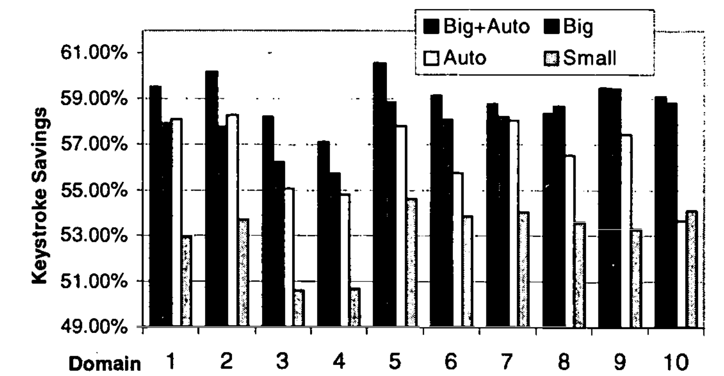

**Figure 1: Comparison of Predictive Models**

Not surprisingly, the 'Big+Auto' configuration, with its equally weighted general and specific components yielded the best results, followed in turn by 'Big', 'Auto', and 'Small'. The almost 2% advantage of 'Big' over 'Auto' is also reasonable given its much larger training text size. However this effect is also due to the fact that the conversants were generally not experts in these domains. This boosts the relative importance of those testing text statistics correlated with *conversation* in general and the 'Big' training text constitutes a fairly large and therefore reliable sample of such general conversational statistics.

The 'Small' training text is only about 1/40th the size of the 'Big' training text, yet it covers a significant fraction of the domains that 'Big' does, thus rendering it a far less reliable sample of general conversational statistics. This accounts for our most interesting result which is the nearly 3% advantage of the 'Auto' configuration over the comparably-sized 'Small' configuration. Thus, for a given model size, using a model derived from text of the same domain as the testing text yields better prediction than using a model derived from a more general pool of text. As noted earlier, this is because the 'Auto' models provide a better match between the training and testing text word usage patterns.

**Table 1: Average KS for four configurations**

| Config. | Ave KS |
|---|---|
| Big+Auto | 58.74% |
| Big | 57.81% |
| Auto | 55.91% |
| Small | 53.00% |

Finally, we emphasize that the 'Big+Auto' configuration exceeds the 'Big' configuration by nearly 1%, despite the fact that it is only very slightly larger than the 'Big' configuration. This reinforces our main finding of the benefit of using domain-specific prediction models and suggests that as we consider larger and larger total model storage capacities, we expect the greatest incremental improvements to result from additions of domain-specific training text rather than of general text. This is the subject of ongoing studies.

## DISCUSSION

Since it appears that domain-specific databases can provide substantial improvements in word prediction, where can appropriate databases be found? Existing corpora such as the Brown, Switchboard, and British National Corpora consist of text categorized roughly along various domain boundaries – topic, genre, sophistication, etc. By dividing these corpora along these categories, a series of baseline domain-specific models could be derived.

Our research team is also investigating the feasibility of culling appropriate databases from the internet using an autonomous "web crawler" (3). While the web offers a wealth of text – perhaps as much as a trillion words – this text varies widely in content, style, and sophistication. We have developed a prototype web crawler capable of searching out and retrieving specific genres of text. Such a system opens up exciting new possibilities for domain-specific word prediction since it can potentially produce very large databases – an important determiner of word prediction accuracy (1).

This paper has focused on prediction databases specific to a particular *topic* domain. The model can clearly be extended to other domain classification schemes such as style, formalness, or genre. For example, at different points during a day, a student might be working on an essay for class, a work of fiction, and a letter to a friend. By switching domains between appropriate text genres (essay, narrative, and correspondence), a word prediction system could take advantage of the word usage and syntactic peculiarities of each genre to offer more appropriate predictions.

The performance enhancements described above assume that the appropriate ngram model is always being applied to a conversation. Certainly this could be true if the augmented communicator manually switched databases as needed. Of more interest, however, is a system that *automatically* switches databases. We are currently developing a system that utilizes local conversational context to determine the current domain. Preliminary results show that on a limited set of topic domains, 80% domain switching accuracy is possible.

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EVALUATING COMMUNICATION RATE IN INTERACTIVE CONTEXTS

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ABSTRACT

This research project focuses on the analysis of communication rate during conversational interaction. We report on our current research involving: a) the development of a computer assisted tool for transcribing interactive discourse, b) a protocol for segmenting and analyzing meaning and information transfer and c) initial findings from three augmented communicators and their partners.

BACKGROUND

One of the primary goals of the augmentative communication field has been to speed up the productions of augmentative communicators, which can be summarized as the *rate problem* (1). Commonly calculated as a ratio between the number of physical actions or units of information produced by an individual or dyad over a standard period of time, the majority of research in communication rate has focused on non-interactive tasks in experimental contexts (2,3,4,5,6). Relatively little attention has been paid to the measurement of communication rate during social interaction, though it is the primary communication activity for the majority of augmented communicators. Interactive rate measurement problems include:

a) Accounting for the augmented speaker's message preparation time.
b) Dealing with speaker overlaps
c) Accounting for message co-construction during conversation.
d) Determining the information conveyed by a telegraphic utterance.

In each of the these cases, the application of the words-per-minute measure may underestimate the augmented speaker's communication rate and obfuscates the temporal dynamics and each participant's contribution to the interaction. The empirical assessment of interactive communication rate is critical to understanding what communication rates (individual or dyadic) that are necessary to sustain and shape various interactive forms of communication. (7,8).

RESEARCH GOALS

The goal of this project is to develop a comprehensive approach to measure the temporal and content characteristics of interactive communication that takes into account interactive and device-related phenomena unique to augmentative communication. This includes developing:

- Transcription technologies to improve the ease and precision of transcribing interactive communication involving augmented speakers.
- Transcription procedures to permit the analysis of interactive discourse involving augmented speakers using a variety of augmentative technologies and communication strategies. This system accounts for both temporal and proposition-type information as well as grammatical structure, co-construction and omissions.
- A preliminary temporal and informational analysis of 4 interactions involving augmented speakers and their non-augmented interlocutors.

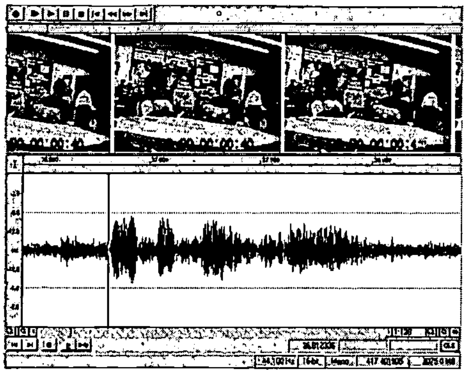
This first phase of research largely focuses on the development of a standard system of classifying different types of units that represent utterance content, specific structural information about those utterances, and information on co-construction and omission. These units and information can then be investigated as to their interrelation with communication rate.

## NOVEL METHODOLOGIES

Implementing an Effective Transcription Tool: Sonic Foundry's SoundForge

Digital video presents many potential advantages for interaction analysis, but many current software tools are inaccurate, cumbersome and inefficient (takes 1 hour to transcribe a minute of video). The software package Sound Forge functions as a media player/editor with sound wave and video interface. The researcher can directly views and manipulates the media (expand, contract, forward, backward). Transcriptions are made by directly selecting the segment of sound or video, then annotating. The annotations including associated temporal information (e.g., onset, offset, duration) can then be copied into a text file or spreadsheet for analysis. Transcription with SoundForge markedly improves transcription efficiency (up to 75%), as well as the temporal precision of the transcription.

Figure 1: SoundForge Screen



Designing an Analytical Tool: BU/SU Analysis

Segmentation of utterances into *Big Units* (BUs) represents our first attempt at dividing linguistic and gestural interaction into segments that represent both meaning and structure. The criteria for delineating these units are based on both ideas in basic linguistic theory, theories of disordered communication, and observations of augmentative interactions. The following are examples of BUs.

- *Transitive verbs, their subjects and NP or infinitival arguments;*
- *Intransitive verbs and their subjects; passive verb, its subject and its by-phrase;*
- *"To be" verbs, their subjects and predicates; Yes/No responses;*
- *Sentence-level adverbs; Question words or other questioning strategies;*
- *Phrase-level conjunction; idiomatic expressions; adjunct prepositional phrases*

BU can then be segmented into 'Small Units' (SUs). These units can be used to understand the grammatical complexity of utterances. BUs and SUs are described in detail elsewhere (8)

## PRELIMINARY INVESTIGATION OF INTERACTIVE COMMUNICATION RATE

The first phase of our investigation has focused on obtaining distributional characteristics of BUs for augmented and natural speakers. Data reported here is focuses on three augmented speakers and their partners during different communication activities (lecture, conversation) and with different communication media (language board, electronic device, natural speech) (see Table 1). Although our analyses are in a very preliminary phase it is interesting to note the 10 – 15 fold disparity in BU duration and a 10- to 30 fold discrepancy for BUs per minute, for augmented versus natural speakers. The formulation and production costs associated with speaking is particularly revealing in the regression analyses in which there is statistically significant positive correlation between BU druration and the number of words per BU for each of the three augmented speakers. In contrast, for the natural speakers, no statistically significant relationship between the measures is noted and the correlation approximates 0. Also note the disparity of Carol's BU rate compared to Jeff's and Roys, reflecting her role as a communication board facilitator versus conventional addressee.

Table1:
Frequency and Duration Data for Augmented and Natural Speaker Communication.

| Speakers | Number of Words | | Speaking Duration | | | Regression: BU Dur. X Words/BU | |
|---|---|---|---|---|---|---|---|
| | Total | Median Words/BU | Total (in minutes) | Median BU (in seconds) | BU per Minute | R-squared (adjusted) | Prob. |
| *Augmented* | | | | | | | |
| Ted (VOCA/Instruct) | 36 | 1.5 | 4.6 | 15.5 | 3.1 | .35 | 0.02 |
| Jen (Board/lect) | 128 | 2 | 8.7 | 9.6 | 5.1 | .65 | 0.01 |
| Gerry (Board Conv) | 20 | 3 | 2.1 | 16.4 | 3.3 | .53 | 0.04 |
| *Natural* | | | | | | | |
| Jeff (Ted) | 100 | 2 | 0.5 | 1.0 | 58.0 | .14 | 0.25 |
| Roy (Ted) | 126 | 2 | 0.6 | 0.8 | 58.1 | .00 | 0.37 |
| Carol (Gerry) | 43 | 3 | 0.2 | 0.6 | 110.5 | .00 | 0.39 |

## DISCUSSION

Our research has primarily focused on the development of the tools for analyzing interactive communication rat with an emphasis on the quantitative analysis of meaning (i.e., Big Units). Although preliminary, We are beginning to reveal the temporal costs associated with interactive communication. The next focus of our work will be to detail the role of gesture and co-construction in the message production process.

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# Computer Access and Use
# (Topic 3)

# A SURVEY TO SUPPORT THE DEVELOPMENT OF AN INTERFACE DEVICE FOR INTEGRATED CONTROL OF POWER WHEELCHAIRS, COMPUTERS, AND OTHER DEVICES

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## ABSTRACT

A survey was developed to provide professional and consumer input into the design and development of an interface device for integrated control of power wheelchairs, computers, and other devices. The purpose of the survey was to collect and analyze data on the various components considered essential in the design of a prototype integrated controller. The web-based survey allowed for recruitment, consent, and survey completion to occur through the Internet or e-mail exclusively. Survey results indicate a strong desire for the use of integrated controls.

## BACKGROUND

Many people who rely on powered wheelchairs have limited abilities to physically control a variety of needed output devices to perform common daily activities (1). A person with high-level spinal cord injury, who controls a powered wheelchair with a proportional chin mounted joystick, might need a computer for educational, vocational, or personal pursuits. A person with cerebral palsy, who controls a powered wheelchair with a proportional joystick operated with one foot, may need to control an augmentative and alternative communication (AAC) device.

In these and other cases, the clinician and consumer often identify only one control site as reliable, effective, and acceptable relative to performance and comfort. In addition, controllers and devices require space in an already limited “real estate” available to the user. Current technology solutions to multiple assistive device needs necessitate the use of either separate or “distributed” controllers placed in different locations or separate controllers interchanged at the same location. Consequently, the use of distributed controls results in cumbersome arrangements of input devices or may limit the number of assistive devices that an individual can operate (2).

Development of integrated control systems has attempted to address the problems of distributed controllers (3, 4). However, these systems have not developed or evaluated a universal interface technology. In addition, minimal information is available which identifies factors for recommending appropriate integrated controls (2). Tools for monitoring the access rate for comparing various input methods for AAC users are just now becoming available (5).

Some wheelchair control systems offer the option of an "environmental control" function. This typically provides four switch outputs that can be activated when the wheelchair joystick is moved in the corresponding directions (up, down, left, right). Accessory items are available that use those switch outputs. For example, those switch outputs may be converted to mouse emulation for use with a computer or AAC system. However, since the proportional information available from the joystick position has been reduced to four switches, pointing performance has been reduced as well.

## OBJECTIVE

A Likert-type survey was developed and distributed as part of a RERC project encompassing the design, development, and evaluation of strategies and devices to promote the electronic integration of external devices with powered wheelchairs and the single control of these devices, ensuring their compatibility and usability. The purpose of the survey was to collect and analyze data on the following issues considered essential in the design of a prototype integrated controller:

- identification of all major proportional control formats used in powered wheelchairs, computer access, AAC, robotics, entertainment, and other areas of assistive technology;
- identification of specific outcomes that lead to the definition of the control bus adapter(s).
- determination of whether multiple adapters are more commercially viable than a single adapter that does everything.

## METHODS

After survey development, a recruitment announcement was distributed through email and the Internet including the following listserves: 1) the RESNA SIG-11/09 listserves, 2) WheelchairNet listserve, and 3) ACOLUG (Augmentative Communication On Line User Group) listserve,

Participants fell into the categories of consumers and professionals. Consumers were considered users of powered wheelchairs with proportional control. Professionals included service providers to consumers who would benefit from integration of electronic external devices, individuals pursuing research in the development of controllers for assistive technology, and manufacturers.

The project began when the investigator activated the web site for the completed survey and posted recruitment notices. Upon receipt of a recruitment announcement as a listserv posting or personal e-mail message, potential respondents were asked to return e-mail consent. Upon receipt of consent, the sample respondents were given the web site address and password for the survey. Security measures in designing the web site and providing a password controlled access to the site and avoided duplication of responses.

The survey required approximately 20-30 minutes for completion. No response was associated with a particular individual, and the data was tabulated and analyzed in a manner to insure confidentially and anonymity of participants.

## RESULTS

Data from 14 professional respondents were analyzed using descriptive statistics. Clinical service providers made up the majority of professional respondents (61%) and the second largest group was researchers (23%). Only one manufacturer and one supplier completed the survey. In addition, five consumers completed the survey.

All of the professional respondents felt that an integrated device would be useful for their clients. In addition, 100% of the respondents felt that an integrated device would be useful for people with disabilities in general. When asked to identify which was more useful for the client, a single integrated control or multiple device adapters, 83% identified a single all-purpose integrated control and 17% preferred the availability of multiple device adapters.

The following functions/options that should be performed by an integrated control were identified on an open-ended question: computer access/mouse (92%); ECU/EADL control (54%); AAC control (38%); wheelchair accessories (31%); switches/scanning abilities (23%). Additional single responses included the following suggestions: removable from chair, auto detection of device, user parameter adjustments, ability to control more than one device at a time.

Respondents identified the following communication protocols for use or access: Universal Serial Bus (USB), Apple Desktop Bus (ADB), Infrared (IRDA), parallel port/serial port (RS232), Radio Frequency (IEEE standards or/Bluetooth), General Input Device Emulating Interface (GIDEI). In addition, safety concerns included the following suggestions: clear indication of what device is in use; immediate "kill switch"/emergency shut off; backup/emergency access; interference with other devices.

Consumer responses were in agreement with features and functions for an integrated controller as well as concerns about safety. Only two respondents had tried an integrated control to operate multiple devices. Of these, one found the controller to be very easy to use, while the other respondent found the controller to be difficult to use. Three respondents were interested in using their wheelchair controller to control other devices. The respondents indicated a preference for using an integrated controller for environmental control and computer access.

## DISCUSSION

The results from this survey confirm the market interest in integrated controls. While the expected performance improvement as a result of a true proportional control is as yet unknown and therefore unappreciated, the survey results provide some justification for the continued development of integrated controls.

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# TOWARD DEVELOPMENT OF AN INTERFACE DEVICE FOR PROPORTIONAL MOUSE EMULATION THROUGH A POWER WHEELCHAIR CONTROLLER

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## ABSTRACT

A Joystick to Mouse Adapter is being designed which will allow a power wheelchair joystick to provide proportional control of a computer cursor. This will provide people with the ability to use a single input method for both devices. A wheelchair controller could provide proportional mouse emulation either by directly controlling the position of the computer cursor or by controlling the speed and direction of the cursor. The Joystick to Mouse Adapter will be used to test these different control methods. More generally, the Adapter will be used to evaluate the feasibility of an intermediary device for translation between various input devices and assistive technologies.

## BACKGROUND

Many people who use power wheelchairs also require access to computers and other assistive technologies, such as augmentative and alternative communication (AAC) devices and Electronic Aids to Daily Living (EADLs). Often, each device has a separate input method. However, a person may have a limited ability to physically operate these devices, and may only be able to achieve reliable and effective control at a single site (1). In this situation, the person may attempt to control multiple input devices mounted at the same site, or may rely on a caregiver to switch input devices when the person wishes to change tasks. A third alternative is to use an integrated control system. An integrated control system allows a person to operate several pieces of assistive equipment through a single, universal input device (2).

One particular application of an integrated control system is to provide computer access through a person's wheelchair controller. Some devices already translate between a wheelchair joystick and a computer, such as the DrivePoint (Bloorview MacMillan Centre, Toronto, Canada) and MouseMover (Dynamic Controls, Christchurch, New Zealand). However, these devices translate information about joystick position into switch inputs which allow a person to control the direction of cursor movement, but do not provide proportional control of cursor speed. It would be desirable for a proportional wheelchair joystick (one which allows the driver to control both wheelchair direction and wheelchair speed) to also control both cursor direction and speed on the computer.

A joystick could control the computer cursor using either position control or velocity control. With position control, the position of the cursor on the computer screen is a function of the joystick position. With velocity control, the velocity (direction and speed) of the cursor is a function of the joystick position (3). In order to select a stationary icon, the user of a position-control system will move the joystick to a position associated with the position of the icon on the screen. The user of a velocity-control system will move the joystick once to select a direction and velocity for the cursor, and move the joystick back to the center in order to stop the cursor on the icon.

Some research has been conducted to compare these control scenarios. Jagacinski and colleagues had subjects use a single-dimensional joystick to capture on-screen targets (4). Fitts' Law was found to apply whether the joystick controlled cursor position or cursor velocity. The Fitts' Law slope was steeper for velocity control than for position control, such that position control was faster for targets with index of difficulty above 4.7 bits. An index of difficulty of 4.7 bits corresponds to a situation in which the distance to a target (i.e. an icon on the computer screen) is 13 times the width of the target. If the distance the cursor must travel to the icon is less than 13 times the width of the icon, then velocity control would offer faster performance. If the cursor must travel a longer distance, then position control would offer faster performance. A higher Fitts' Law slope for velocity control, as well as faster movement times for position control at high index of difficulty, was also found for an isometric (force-sensing) joystick (5). These studies indicate that selection of a stationary icon with a position-control system is generally superior to selection with a velocity-control system (3). However, position control is not exclusively superior. The advantage of position control is greater for longer movements, or for selecting smaller icons. For targets with a sufficiently low index of difficulty, velocity control is superior.

Position control has other potential drawbacks. In a position-control system, it is necessary to hold the joystick at a desired position while also performing a mouse button click. If the joystick is not held steady it will return to the center position, causing the computer cursor to return to the center of the screen. With velocity control, a person can release the joystick and the cursor will stay in one location, since the center joystick position corresponds to zero velocity. The person can then concentrate on performing a button click.

Also, position-control systems and velocity-control systems will be sensitive to a loss of calibration in different ways. If a position-control system is properly calibrated, there will be a joystick position that corresponds to every location on the computer screen. If calibration is lost, some screen locations may have no corresponding joystick position. Those screen locations will be inaccessible. This situation can arise because communication between the mouse and the computer typically takes place in one direction; the computer receives information about the mouse position, but sends no information about cursor position.

When a velocity-control system is properly calibrated, each joystick position will correspond to a particular cursor velocity. In particular, the cursor will have zero velocity when the joystick is at the center position. If this calibration is lost, the computer will not recognize the correct center position for the joystick. The cursor may then drift even when the joystick is centered.

These calibration problems can be solved by detecting when the joystick is in the center position and either sending the computer a command to center the cursor (in position control) or by sending signals to indicate no change in cursor position (in velocity control). The velocity control solution can be implemented entirely by hardware connected to the joystick, while the position control solution will require altering the computer's software to accept the centering command.

## STATEMENT OF THE PROBLEM

While research indicates that selection of a stationary icon with a position-control system is generally superior to selection with a velocity-control system, this superiority could be mitigated by factors affecting real-world computer control. It is desirable to evaluate whether position control or velocity control is most useful for cursor control in an actual graphical user interface.

## DESIGN

A prototype Joystick to Mouse Adapter will be used to determine whether position control or velocity control is most useful for joystick control of a graphical user interface. The Adapter will intercept control signals from a wheelchair joystick. It will first determine whether to use the joystick information for wheelchair driving or for computer control. If the joystick is being used to drive the wheelchair, the control signal will proceed to the wheelchair controller as usual. If the joystick is being used to control the computer, a signal will be sent to the wheelchair controller to suspend driving.

When the joystick is being used for computer control, the horizontal and vertical position of the joystick will be used to determine a desired cursor position (in position-control mode) or a desired cursor velocity (in velocity-control mode). The Adapter will send a signal to the computer, and the computer will respond to this signal as if it originated from a standard mouse. Two switches on the adapter will be used as left and right mouse buttons. External switches can be used as well.

The Joystick to Mouse Adapter will initially translate between a single input device (an Invacare wheelchair controller, Invacare Corporation, Elyria, Ohio) and two target devices. These target devices will include a computer using either the Microsoft serial mouse protocol or the Microsoft PS/2 mouse protocol and an AAC system that accepts mouse input for direct selection.

## DISCUSSION

A wheelchair joystick could control a computer cursor using either position control or velocity control. A person's performance with either method could be affected by factors such as the size and spacing of icons in different computer applications, use of mouse buttons, and loss of calibration between the joystick signal and the cursor position. The Joystick to Mouse Adapter will be used to evaluate both methods. These results will contribute to the development of integrated control systems for power wheelchairs and computers.

The Joystick to Mouse Adapter itself represents one approach to an integrated control system. In this approach, an independent interface device acts as a translator between other devices. Ideally, this system would require minimal alteration of the component devices since the interface device will make use of their existing communication protocols. Once the Adapter has been used to test the feasibility of this approach, it will be expanded to accept input from other wheelchair controllers. The Adapter will eventually provide the basis for a more general system, which will act as a translator between a single input device (such as a wheelchair controller) and multiple external devices (such as computers, AAC devices and EADLs). Such a universal interface method would allow consumers to integrate the assistive technologies and input methods that are best for them, without concern for limitations in compatibility between devices.

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# USING QUADRATURE EMULATION TO CONNECT PROPORTIONAL CONTROLS TO PERSONAL COMPUTERS THROUGH A STANDARD MOUSE

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## ABSTRACT

An electronic circuit has been developed that allows a power wheelchair joystick to be used as a computer mouse. The circuit works by translating the joystick's proportional signals into quadrature signal patterns the mouse normally samples through rotary encoders. The joystick can be connected to a PC computer through a commercial mouse controller chip. Clinical applications of this circuit include integrated controls and the option of using proportional controls not currently available with mouse port connectivity.

## BACKGROUND

Individuals with upper extremity impairments are sometimes unable to use a commercial pointing device such as a mouse or trackball. Special pointing devices are available for individuals with good head control (1,2). Software is available that can translate game port input signals from a game control into mouse movement (3).

The Human Engineering Research laboratories (HERL) has built and investigated several isometric joystick prototypes over the past decade for use as alternative controls on electric powered wheelchairs (4,5). We are currently investigating whether individuals with upper extremity impairments can effectively perform mouse cursor manipulation with this type of joystick.

The HERL isometric joystick offers two signal sources that can be sampled and translated into mouse format: Serial RS232 data (12 bits, X and Y axis, 100 Hz used for data collection) and Speed and Direction analog signals generated by the joystick to emulate typical position sensing joysticks. This interface is plug compatible with most power wheelchairs. While the digital data most accurately represents the operator's hand forces, the analog signals are a commercial standard used on many electric wheelchairs; a mouse translator for this format would have application beyond our immediate research project.

## PROBLEM DESCRIPTION

We desired to connect a research analog control to a computer mouse port. We considered developing micro controller code that would permit the isometric joystick to transmit directly to a computer using a standard mouse protocol such as Microsoft Serial or PS/2. This approach would be tedious, difficult to debug and require an additional handshaking line. We searched for any commercial mouse controller chips that would accept asynchronous RS232 or analog voltages as input. The mouse controllers chips we reviewed all used quadrature sampling. We did identify one mouse controller that took input from an integrated Hall effect transducer (6). This chip was deemed unsuitable because it was a very small surface mounted device and not practical to rewire.

## RATIONALE

Based on our product review, we decided to try and create a hardware circuit to translate the proportional signals from our isometric joystick into quadrature signals commercial mouse controllers normally receive at their input pins. An inexpensive, massed-produced mouse controller chip would take care of all the nuances of interacting with the target computer including managing all the button protocols. The target computer could use a standard mouse driver. Quadrature emulation should also work with mice and trackballs used with Macintosh and Sun platforms. A future clinical application for this hardware could be an integrated control allowing consumers to access their computer with the same joystick they use to drive their wheelchair. A wheelchair with an infrared cordless mouse could automatically "couple up" when driven within range of a computer station.

## DESIGN

Mice and trackballs translate operator movements into two streams of digital data. The rotating ball drives two orthogonal shafts each connected to a separate shutter wheel. Each wheel spins between a light source and two phototransistors. When one of the phototransistor is exposed to a light pulse, its impedance drops sharply and it pulls an input pin on the micro controller to a high state. The phototransistors are arranged 90 degrees out of phase generating different pulse patterns for clockwise and counter clockwise rotation (7). This technique is called quadrature and the stream of two bit pairs (dibits) is an application of Gray code. The controller uses these dibit sequences to calculate the speed and direction of the X and Y shutter wheels and sends updated values to the computer every 25 to 30 milliseconds. Since the controller's actions are based solely on the state of its input pins, external digital data can be substituted with frequency representing magnitude and Gray code sequences indicating direction.

Three lines from a wheelchair joystick are required to define steering intent: a reference line set at +6 volts, an X-axis line (Speed) and a Y axis line (Direction). The Speed and Direction lines are DC analog signals that vary from +4.8 volts to +7.2 volts. This voltage range represents full reverse to full forward on the Speed line and hard left to hard right on the Direction line. When compared with the reference, these signals are bipolar and swing between -1.1 and +1.1 volts. Our task was to translate these X and Y analog signals into the required Gray code dibits - a multi-step process.

## DEVELOPMENT

In order to translate a wheelchair joystick into a mouse, we had to amplify the joystick signals, convert the bipolar signals into absolute values, generate pulse streams with frequency proportional to signal magnitude and translate the pulse streams into sequencing Gray code dibits. We built a simple complementary amplifier with NPN and PNP transistors. We were able to achieve adequate gain with a split +3, -3, battery power supply assembled from four standard 1.5-volt D cells. We used the same batteries in the digital section, by shifting the ground reference to obtain a one-sided, +6 volts. A voltage comparator was used to track signal polarity. The amplified bipolar signals were used to drive four infrared LEDs (X and Y axis with a separate LED for each polarity), the LEDs. We used phototransistors to read the LED and obtain X and Y axis absolute values. Magnitude-to-frequency conversion was performed by two 555 timers configured as square wave generators with our phototransistor inserted in the RC timing section. The frequency varying pulse stream was converted to sequencing binary two bit values by driving the clock of a four bit binary counter. Any two adjacent output pins from the binary counter can be sampled. Choosing a different pair of pins one is one way to change the gain. We translated the two bit values from the binary counter into two bit Gray code with two Exclusive Or Gates. One Gray code bit is created by an Exclusive Or of the two bits currently on the counter. The second Gray code bit is created by an Exclusive Or of the least significant counter bit and the direction status bit sampled by the voltage comparator. When the direction status bit is set to one, the resulting Gray code automatically cycles forward through 00,10,11,01 and the mouse will send positive updates to the computer moving the cursor either up or to the right. When the direction status bit is zero, the Gray code pattern reverses to 00,01,11,10 and the computer cursor moves downward or to the left.

The last step was to interface the X and Y Gray code streams to a mouse chip. We used photo couplers to minimize the risk of damaging the mouse's sensitive detection circuits. Our optical couplers were wired in parallel with the existing phototransistors inside the mouse. We blocked the mouse's internal LED light references with small pieces of electrical tape. The internal phototransistors stayed in a high impedance state and our external phototransistors became the signal.

## PROGRESS TO DATE

A working "proof of concept" prototype has been fabricated (Figure 1). LEDs were included throughout the trial circuit to assist in tracking the logic. At low frequencies, we clearly observed the mouse cursor advancing one pixel each time the Gray code LEDs transitioned. When the voltage comparator switched logic states, the cursor reversed direction. We found experimentally that a pulse rate ranging from zero Hertz (joystick centered) to about 250 Hertz (joystick fully deflected) provided comfortable cursor control.

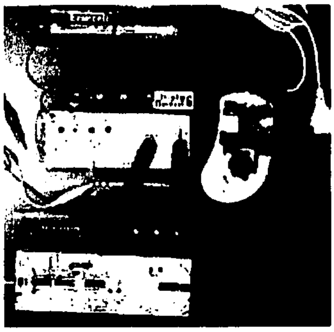

Figure 1. Experimental joystick to mouse circuit.

## EVALUATION/DISSCUSSION

Six unimpaired individuals from our lab have informally evaluated the prototype joystick mouse. All were readily able to direct the cursor around the screen at various velocities and directions without difficulty. The proportional response is similar to commercial products, giving us confidence that our Gray code algorithm will work effectively at the cursor velocities needed for normal computer interaction.

The prototype amplifier needs to be tuned with trimmers to maintain good diagonal cursor movements; a sign that our amplifier is non-linear. In order to obtain digital data and repeatable accuracy in upcoming isometric joystick studies, we plan to carry out the digital to Gray code transformation using the isometric joystick's internal micro controller, coupling the final Gray code to a mouse chip. A microprocessor-based Gray code generator will make it possible to investigate more sophisticated force-to-frequency algorithms.

Quadrature emulation circuits show promise as a method for interfacing analog controls to computer mouse ports. Our trial circuit has served us well by demonstrating the viability of this technique. Improvements for the next prototype should include dual IC packages, eliminating the LEDs and substituting more linear voltage-to-frequency converters. The major component count can be reduced to four transistors and four logic chips allowing the entire circuit to fit on a single 2" X 6" board. We will continue to investigate our analog hardware for clinical applications.

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# EFFICACY OF THE WORD PREDICTION ALGORITHM IN WORDQ™

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## ABSTRACT

Word prediction software is a tool used by individuals who have physical difficulty selecting keys as well as by individuals who have cognitive difficulty with spelling. The quality of word predictions is an important consideration for both purposes. This paper describes simulations to test the prediction algorithm in a new product called WordQ. Keystroke savings with the most successful configuration of WordQ ranged from 46% to 53% depending on the text source. The average number of correct keystrokes needed to make a correct prediction ranged from 1.73 to 1.82.

## BACKGROUND

Word prediction programs were originally designed for individuals with physical disabilities to reduce the physical demands of typing (1). Relatively recently, these programs have been adopted by educators to provide assistance to students with learning difficulties that impact on the mechanical aspects of generating text such as spelling (2). Commercial word prediction programs have gradually begun to include features specifically targeted for this purpose, such as integrated text-to-speech capabilities. Among other things, speech feedback allows a user to browse through the choices in the prediction list with the keyboard or mouse and have each choice spoken aloud. A new product developed by our group, WordQ, further integrates this type of text generation assistance with the software that people typically use for word processing on personal computers. Details about WordQ's features can be found in (3) and on the world wide web at www.wordq.com.

Although products like WordQ tend to include a large number of user-interface features, the quality of the word predictions remains a central issue. For individuals who have physical difficulty targeting the correct key, high-quality prediction means higher keystroke savings, and a corresponding reduction in the physical difficulty of entering text. For persons with spelling difficulties, a good prediction algorithm reduces the number of correct keystrokes that need to be supplied before the desired word appears in the list.

The prediction module in WordQ combines basic knowledge of word usage with optional customization to each user's vocabulary. The base language model was developed by analyzing a large sample of text gathered from the Internet. This model incorporates word and word-pair frequency statistics as the basis for predictions. The word-pair information influences the prediction algorithm directly: words that tend to follow the user's previous word are given a higher priority. As well, the language model can be set to adapt with use so that the words that a person commonly uses gradually become more likely to be predicted. The model can also learn the user's common word pairs.

## RESEARCH QUESTIONS

The purpose of the simulations described in this paper is to estimate some basic performance statistics for WordQ's prediction algorithm. What percent keystroke savings is possible under simulation conditions? How many correct keystrokes must a user typically supply before the correct prediction is made? How do these results depend on the main components of the WordQ prediction algorithm: use of word-pair knowledge and adaptation?

## METHOD

WordQ's pre-release source code was modified to permit these simulations. During a simulation, the program opened a text file and injected each character to the prediction algorithm in turn as if it had been typed. Table 1 contains a short description of the three diverse text sources that drove these simulations. These documents were written by three different individuals. After each character was injected, the resulting predictions were compared to the original text to keep a running total of performance statistics.

| Sample | Description | Words |
|---|---|---|
| A | Satirical social commentary | 58,422 |
| B | Political analysis/biography | 14,030 |
| C | Scientific dissertation | 44,127 |

Table 1: Description of text samples used in simulations

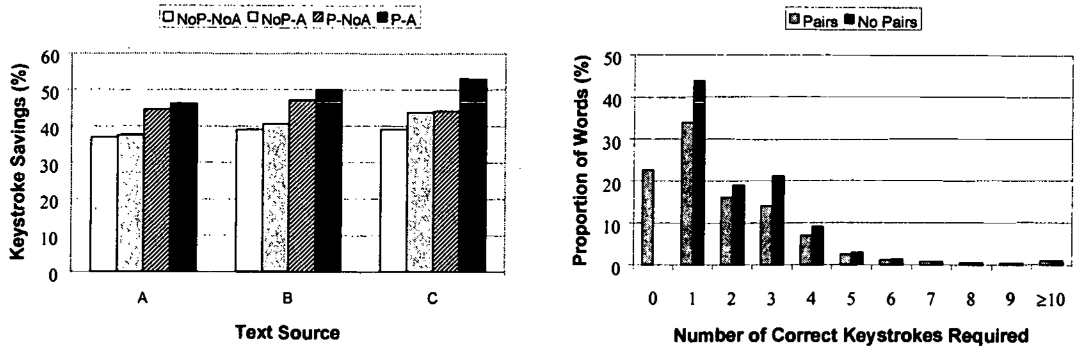
Along with the three text sources, WordQ's two main prediction features (use of word pairs and adaptation) were systematically manipulated, resulting in a total of 12 simulations. Each simulation started with the same language model, which featured a base vocabulary of 15,000 words and a backup dictionary on disk of 60,000 words. To test validity, each simulation was preceded by a rehearsal run which generated a detailed prediction log showing input characters, the resulting predictions and the simulator's scoring decisions. The log was verified manually before the full simulation.

## RESULTS

Table 2 shows the performance statistics for the 12 simulation runs. The keystroke savings, also illustrated in Figure 1a on the next page, range from 37.0% to 53.1% depending on the features enabled and the text source. The results show that use of word pair information adds approximately 5-10% to the overall keystroke savings. Adaptation made a relatively small contribution to savings, except for the case of text source C, in which there was an apparent interaction between use of word pairs and adaptation. This is not surprising given the unusual nature of the text in C (a scientific dissertation). Figure 1b shows the distribution of required correct keystrokes before the desired word is displayed in the prediction list for two simulations contrasting the use and non-use of word-pair information. When WordQ took advantage of word pairs, nearly 23% of words were predicted after no keystrokes, through next word prediction alone.

| | | Keystroke Savings (%) | | Mean Req'd Correct Keystrokes | |
|---|---|---|---|---|---|
| | | No Adaptation | Adaptation | No Adaptation | Adaptation |
| Text A | No Pairs | 37.0 | 37.5 | 2.32 | 2.29 |
| | Pairs | 44.6 | 46.3 | 1.89 | 1.80 |
| Text B | No Pairs | 39.1 | 40.6 | 2.36 | 2.27 |
| | Pairs | 47.1 | 49.9 | 1.90 | 1.73 |
| Text C | No Pairs | 39.2 | 43.8 | 2.69 | 2.40 |
| | Pairs | 44.2 | 53.1 | 2.38 | 1.82 |

Table 2: Performance Statistics for simulations with three different text sources. The shaded boxes show the best results, which occurred when both adaptation and use of pairs information were enabled.




(a) (b)

Figure 1: (a) Comparison of keystroke savings for all 12 simulations. (b) Histogram showing the distribution of correct keystroke requirements for text source A only, both with and without pairs information.

## DISCUSSION

In these simulations, WordQ was shown to be able to eliminate approximately half of the required keystrokes, with word pair information playing an important role, and adaptation playing a lesser role, except when the text is on a very specialized subject. These results depend on a simulated user who makes no typing mistakes and always selects the desired word from the list as soon as it appears. Testing with actual users is the only way to determine if these laboratory measures of efficacy will translate into similar measures of effectiveness in the real world.

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# COMPUTER CONTROL USING SURFACE EMG SIGNALS

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**ABSTRACT**

The Muscle Communicator uses electromyographic (EMG) activity to perform cursor navigation and text entry. The rate of text entry using an on-screen keyboard is measured for ten normal subjects using their thumbs and their jaw and three subjects with disabilities using their most controllable muscle sites. Normal subjects attained rates of 5.6 words per minute (wpm) with their thumbs and 4.2 wpm with their jaw and subjects with disabilities attained a rate of 4.3 wpm. All subjects attained rates within the ranges found in the literature for HeadMaster and mouthstick and their rates were higher than those found for scanning and tongue touch pad.

**BACKGROUND**

Many individuals with severe disabilities are only able to use a computer through a single switch interface which is slow and cognitively demanding. The theoretical maximum text entry rate using automatic row-column scanning is 5 words per minute (1). However, it is typical for users to take several minutes to complete one word (1,2). This paper describes the Muscle Communicator, an alternative computer interface that uses surface electrodes to record electromyographic (EMG) activity in muscles with little or no kinetic motion. Cursor navigation is accomplished using three muscle sites, one for cursor control in the x direction, one in the y direction and one for a mouse click. Text entry is accomplished by navigating the cursor over an on-screen keyboard. Alternately, text entry via Morse code is performed using one recording site for a dot and another for a dash. This paper reports the results of ten normal subjects and three subjects with disabilities performing text entry using the Muscle Communicator and an on screen keyboard.

**RESEARCH QUESTION**

Is the rate of text entry using the Muscle Communicator comparable to rates using other alternative access devices? How do the results of people with disabilities compare to those without?

**METHOD**

Ten normal subjects include seven males aged approximately 18 to 50 and three females aged approximately 25 to 40. Subjects with disabilities include three males aged approximately18 to 50 years and relevant information is shown in the table below.

| Initials | Disability | Muscle Site | Usual computer access method |
|---|---|---|---|
| DC | Spinal Muscular Atrophy | Thumb Flexors | Regular keyboard and mouse |
| JG | Spinal Cord Injury | Wrist Extensor | Regular keyboard and mouse – 1 finger |
| RR | Amyotrophic Lateral Sclerosis | Toe Flexors | Regular keyboard and mouse – 1 toe |

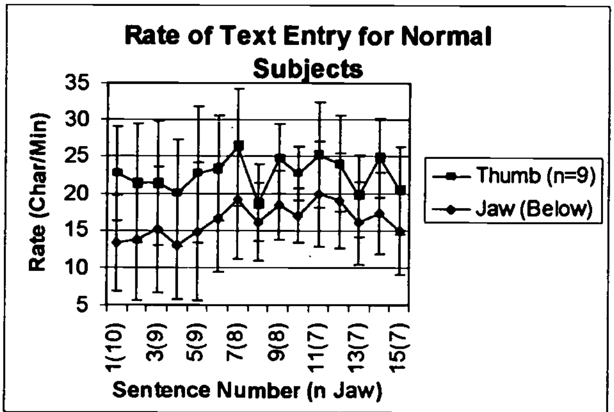
Hardware consists of an interface box that receives analog input from standard electrocardiograph (ECG) cables and outputs digital signals through an RS-232 data port. A Windows NT computer runs translation software that converts the RS-232 signals to either mouse movements or Morse code. The researcher adjusts device sensitivity, input delay (to eliminate switch bouncing) and cursor speed.

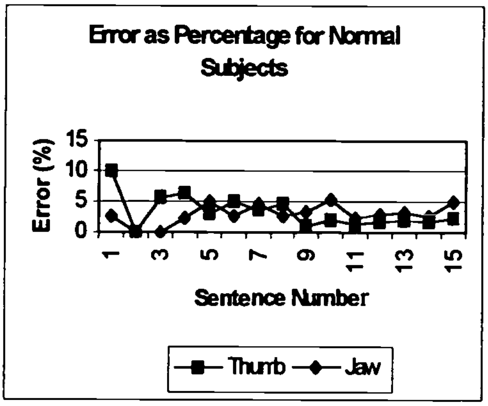
Normal subjects used two sets of muscles to perform the trials. Seven users began by using the right and left thumb flexors, right for x direction and left for y. Three users began by using the right and left jaw muscles to perform a shorter version of the trials. Trials with the thumbs were performed to establish optimum rate. The jaw was used so that comparisons can be made to people with disabilities. It is assumed that most subjects would have the use of their jaw muscles. Subjects with disabilities were assessed for their most controllable muscle sites. All subjects performed the mouse click by raising their eyebrows. The sensitivity of the Muscle Communicator is adjusted until the user indicates satisfaction that the device feedback correlates to their contraction/relaxation.

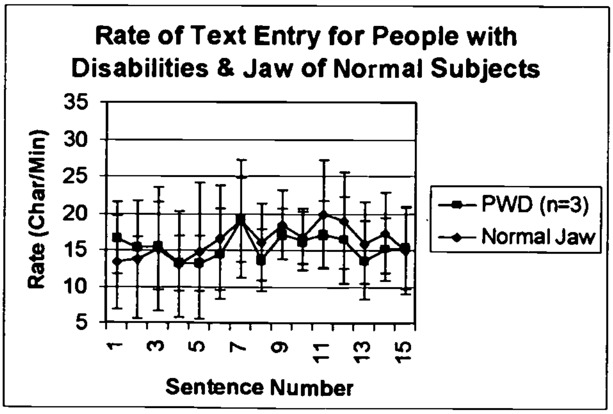
A custom, frequency based on-screen keyboard is used so that memorization of the QWERTY layout is not an advantage for some users. The space key is placed at the top left hand corner and the cursor jumps back to this space after each mouse click. A computer automated program prompts users for input and then stores the time to complete each exercise and test, time to complete each letter, and the number of errors. The researcher increases cursor speed as the user demonstrates accuracy. After practicing the exercises, the subject takes a two-minute typing test. Subjects with disabilities also take the two minute typing test with their present method for accessing the computer.

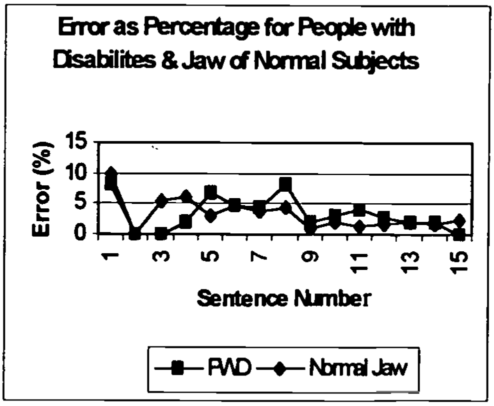
**RESULTS**

The following graphs show rates of text entry for the 15 exercises. The first set of graphs show rates and standard deviation for normal subjects using their thumbs and jaw. Some normal subjects had great difficulty isolating their left and right jaw function and were unable to complete all exercises in the given time. Thus, the sample size is smaller for the later sentences and is indicated on the graph. Error is shown as a percentage, showing that x% of the entries are expected to be errors. The second set of graphs show the rates for subjects with disabilities along with normal subjects using their jaw.



The following chart shows text entry rates for the two minute typing tests.

| Subject Group | Char/min (wpm) | Std. Dev. | Errors/min |
|---|---|---|---|
| Normal Thumbs (n=9) | 28.2 (5.6) | 5.6 | 0.5 |
| Normal Jaw (n=7) | 20.9 (4.2) | 5.4 | 0.4 |
| People with Disabilities (n=2) | 21.6 (4.3) | 6.9 | 0.8 |

## DISCUSSION

Each subject group follows the same trend for the exercises. There is a dip in rate for exercise 8 because that is when the letters at the far side of the keyboard are introduced. The dips at exercises 13 and 15 are when the shift key is introduced. The rates obtained by the people with disabilities were very close to those obtained by normal subjects using their jaw. Rates of text entry for the two minute typing tests are higher than those seen for the 15 exercises because typical sentences are composed of more frequently used letters which are closer to the keyboard "jump back" position. The rate obtained by normal subjects using their thumbs in the two minute typing trials, 28.2 char/min (5.6 wpm) is almost four times higher than the rate observed in a preliminary study using an earlier prototype, 7.1 char/min (1.4 wpm) with 0.1 errors (3). The literature for other alternative access devices reports rates of 3 to 10 wpm for HeadMaster, 4 to 6.6 for mouthstick, 2 for tongue touch pad, and 3.5 wpm for scanning (2,4,5,6). All subjects using the Muscle Communicator attained rates within the range attainable with the HeadMaster and mouthstick and the rates are higher than those for tongue touch pad and scanning.

The number of errors during the exercises is high. Most of the errors occurred when the user became de-synchronized with the letter that the testing program was requesting. When a shifted character was requested, errors were high due to a limitation in the testing program, so they were disregarded. Once the user learns to control each of the functions, x, y and click, they only need to familiarize themselves with the location of the letters on the keyboard. Even though these exercises were shortened from the set used for Morse Code training, they can be shortened even more.

Device sensitivity, flexibility, and directed cursor control make this device potentially very effective for people with severe disabilities. RR presently types with one toe at a rate of 45.0 char/min (9.0 wpm) with 0 errors. The Muscle Communicator particularly impressed him because he would like to use it instead of scanning when his disease progresses. Future work includes obtaining results from a total of 30 subjects with disabilities. Subsequently, all subjects will be tested for rate of text entry using Morse Code.

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# COMPARISON OF FIVE SOFTWARE INTERFACES FOR COMPUTER HEAD CONTROLS

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## ABSTRACT

Neck movement limitations can reduce a person's ability to use computer head controls. Five methods of compensating for neck movement limitation were evaluated. Twenty-two subjects without disabilities and three subjects with multiple sclerosis performed icon selection exercises using a standard interface and each of the five experimental methods. Increased sensitivity tended to result in improved accuracy. Decreased sensitivity tended to result in increased speed.

## BACKGROUND

Computer head controls allow individuals to control the computer cursor using head movements, providing an alternative to the standard mouse. However, neck movement limitations could reduce a person's ability to use head controls (1).

One way to adapt a head control system to an individual's needs is to alter the sensitivity; that is, how far the cursor moves for a given head movement. Increased sensitivity allows a smaller head movement to result in a larger cursor movement, while decreased sensitivity results in smaller cursor movements for equivalent head movements (2). Another compensatory method is a "joystick mode", in which the user selects a direction using a small head movement, and the cursor moves in that direction until the user returns his or her head to a neutral posture (3). Only a small, sustained head movement is needed to move the cursor as far as desired in the indicated direction.

## RESEARCH AIM

Five compensation methods were compared with a standard head control interface in order to determine whether one or more of the experimental methods is associated with improved performance. If one or more of these methods can make head controls more effective for a larger population, then it would be desirable to incorporate them into future head control systems.

## METHOD

### Experimental Compensation Methods

The ***standard interface*** represented an intermediate sensitivity level against which to compare the experimental methods. Experimental Method 1 used an ***increased sensitivity*** and Experimental Method 2 used a ***decreased sensitivity***.

Experimental Method 3 used a ***speed-dependent sensitivity***. In this method, a high sensitivity was used if a person moved his or her head quickly, while low sensitivity was used in response to slow movements. Experimental Method 4 used both sensitivity and a ***velocity gain***. A velocity gain is a relationship between the speed of head movement and the amount of cursor movement; in other words, the cursor will move a certain distance for a slow head movement but a longer distance for the same head movement performed at a faster speed. While Method 3 only accounted for two levels of head speed (slow or fast), Method 4 distinguished between a continuum of head velocities.

Experimental Method 5 was a ***joystick mode***, as described in the Background.

Mouse minidriver software was developed to present the five experimental methods as well as the standard interface, for a total of six experimental conditions. The software was developed for use with Windows 98 using a Mouse Driver Reference Design (Device Drivers International, Cincinnati OH) and Visual C++ 6.0 (Microsoft Corporation, Redmond WA).

Procedure

Twenty-five subjects took part in this study. Twenty-two subjects did not have disabilities and three subjects had multiple sclerosis.

All six experimental conditions were presented to each subject in a random order. For each method, the subject used a HeadMaster Plus™ (Prentke Romich, Wooster OH) head control system to move the computer cursor from the center of the screen to target icons appearing at various locations on the screen. Targets randomly appeared at any of three distances from the center of the screen and in any of eight directions from the center of the screen, for a total of 24 possible target locations. Subjects attended two experimental sessions, with three conditions presented in each session. Subjects without disabilities performed nine repetitions of the icon selection task for each condition, with 24 targets in each repetition. Among subjects with multiple sclerosis, one subject performed six repetitions of the task for each condition; one subject performed nine trials each with the increased sensitivity and joystick mode methods and six trials for each of the remaining conditions; and the third subject performed three trials with the velocity gain method and six trials for each of the remaining conditions.

## RESULTS

Based on investigator observations and subject comments, changes were made to the velocity gain method after the first two subjects without disabilities, and changes were made to the joystick mode after the first 12 subjects without disabilities. Results for these methods are reported below for subjects who used the final versions of these methods. All three subjects with multiple sclerosis used the final version of each method.

Three measures were used for subject performance. Accuracy is the proportion of icons successfully selected. Throughput is a measure of speed, with units of bits/second.
Overshoot is the maximum distance traveled beyond the icon as a percentage of the distance to the icon from the starting position.

Subjects without disabilities had less tendency to overshoot the target icons when using the decreased sensitivity or the joystick mode (Table 1). Otherwise there were no significant improvements with the experimental methods. Subjects did tend to demonstrate faster performance (higher throughput) when using decreased sensitivity.

| | Standard Interface | Increased Sensitivity | Decreased Sensitivity | Speed-Dependent Sensitivity | Velocity Gain | Joystick Mode |
|---|---|---|---|---|---|---|
| Accuracy | 0.99 ± 0.01 | 1.00 ± 0.001 | 0.99 ± 0.004 | 0.99 ± 0.001 | 0.99 ± 0.005 | **0.89 ± 0.09 †** |
| Throughput | 1.80 ± 0.25 | **1.71 ± 0.25 †** | 1.86 ± 0.23 | **1.56 ± 0.19 †** | **1.19 ± 0.15 †** | **0.58 ± 0.03 †** |
| Overshoot | 0.09 ± 0.06 | 0.11 ± 0.07 | **0.07 ± 0.04 *** | **0.21 ± 0.11 †** | **0.25 ± 0.12 †** | **0.03 ± 0.02 *** |

Table 1: Results of icon selection task for subjects without disabilities. (*): significant improvements compared to the standard interface ($p<0.05$ for paired Wilcoxon tests). (†): significant reductions in performance compared to the standard interface ($p<0.05$ for paired Wilcoxon tests).

The experimental methods provided improved performance for subjects with multiple sclerosis. One subject exhibited significantly higher accuracy with the speed-dependent sensitivity, and reduced overshoot with the joystick mode ($p<0.05$). This subject also experienced somewhat higher accuracy with increased sensitivity, and higher throughput with decreased sensitivity and speed-dependent sensitivity (Fig. 1). A second subject achieved higher accuracy with the increased sensitivity method and reduced overshoot with the joystick mode ($p<0.05$). This subject rated the speed-dependent sensitivity and decreased sensitivity methods as easier to use, although neither

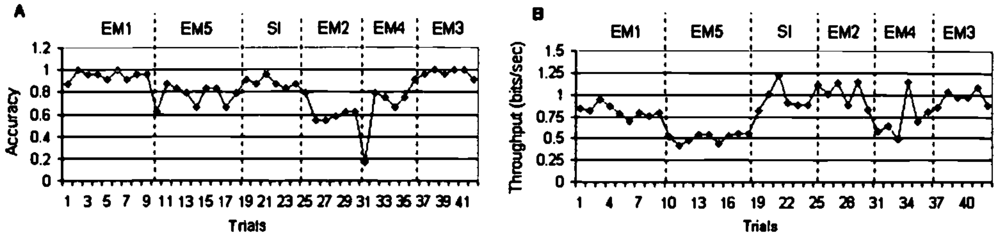


Fig. 1: Results for one subject with multiple sclerosis. (A) Accuracy across trials, in order of presentation. (B) Throughput across trials. Vertical lines represent change of conditions. EM1=increased sensitivity, EM2=decreased sensitivity, EM3=speed-dependent sensitivity, EM4=velocity gain, EM5=joystick mode, SI=standard interface

method resulted in improved performance based on quantitative measures. A third subject had higher throughput with the high sensitivity, low sensitivity, and speed-dependent sensitivity ($p<0.05$ for increased and decreased sensitivity).

## DISCUSSION

Five head control interface methods were designed to compensate for neck movement limitations. Increased sensitivity tended to result in improved accuracy, while decreased sensitivity tended to result in increased throughput. These improvements were not significant for subjects without disabilities, but were significant for some subjects with disabilities. The speed-dependent sensitivity resulted in higher throughput for some subjects with disabilities, but poorer performance for subjects without disabilities. Subjects were less likely to overshoot the target icons when using the joystick mode, and so this interface may benefit some people with motor control difficulties.

These results indicate that different adjustments benefit different individuals based on the individual's strengths and limitations. The results could contribute to a systematic method of customizing the interface to a particular individual. Customizing available options to a particular user is typically a trial-and-error process, and a novice head control user may have difficulty with selecting appropriate settings or physically adjusting these settings. A systematic method for customization could simplify this process, and may also contribute to the design of a head control system that can automatically adjust its settings to the needs of a particular user.

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# LOW VISION WEB ACCESSIBILITY

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## ABSTRACT

This paper describes a project designed to provide web access to users who have low vision disorders. The system, the Universal Accessibility Gateway (UAG), provides for transformations applied at a server level that allow the user to view web pages in a manner most accessible by them. The user views the transformed pages via a standard web browser, thus requiring no specialized hardware or software.

## STATEMENT OF THE PROBLEM

Achieving the goal of universal web accessibility requires not just the implementation of the W3C guidelines, but also specific accommodations for users with disabilities. One of the most common disabilities that impacts users' ability to take advantage of the web is low vision. Low vision problems can take many forms, ranging from acuity problems, to color insensitivity, to loss of peripheral vision. Most commonly, these low vision problems occur as people age, with most seniors experiencing at least some degree of visual impairment. Macular degeneration, the most common age-related cause of visual disability, produces symptoms of color distortions, line distortions, and blindness in the center of vision, which vary in severity from individual to individual. Thus, for example, a person might have a loss of visual acuity that makes reading of normal font sizes difficult in addition to a light transmissive problems making the typical black on white font difficult to read. In order to use a computer, this person could possibly employ assistive devices to cope with the disabilities. Such assistive devices, however, generally have software and hardware demands which are not only costly for the individual user, but which also put the burden on the user to install and maintain and may be incompatible with each other if the user has multiple difficulties requiring more than one assistive device.

## BACKGROUND

The UAG is not the first attempt to provide web access for users with low vision. The two major web browsers, Netscape and Internet Explorer, both have options for enlarging font size, and Internet sites such as Betsie [1] and SETI-search [2] provide font enlargement and sometimes changes in font color for web pages falling within their coverage. Recent work by researchers at IBM in Japan [3,4] uses the WebSphere-based architecture [5] of the UAG and provides for a page simplification, although this technique imposes a burden on web authors or others provide the annotations to accomplish this simplification.

## RATIONALE

Our goal in the UAG project is the development of a system that requires no specialized hardware or software that must be installed by users with disabilities, thus removing the burden for them to find, install, and maintain specialized hardware or software. UAG allows the user, through any standard browser to access web pages served through a proxy that reformats the content of web pages and displays them to the user in a manner most accessible by them. Unlike systems such as Betsie [1], the user may access any web page through this system, not just selected content pages. The system affords individual configuration for each user and has the capability of applying more than one transformation per page (thus, being able to deal, for example, with both acuity and light transmissive disorders for a given user).

## DESIGN

The architecture forms an automated, distributed access framework utilizing WebSphere [5] as a base. Content transformation is performed automatically through this web intermediary architecture on a server infrastructure.

We began by implementing transformations for font and images. For font, we implemented style sheet transformations for font enlargement and corrections for light transmissive disorders that would makes changes in foreground and background colors. For images, we implemented transformations that would allow for image enlargement and contrast enhancement. Each of these transformations can be applied individually or in combination, such that one user might only want to make use of the font enlargement capability, while another might choose to both enlarge the font and change the foreground and background colors. The amount of enlargement and the color combination are at the discretion of the individual user. Through creation of user profiles, these settings are remembered by UAG from session to session.

## DEVELOPMENT

Development has been a multi-group effort, with researchers collaborating across both group and geographical boundaries. Experts in architecture, applications, and HCI came together to satisfy the many demands of scalability, security, utility, and usability.

Intensive design consideration was given to ease of use, particularly since many of our projected users were seniors, often relatively novice computer users. Privacy was another key issue in the design of our system architecture due to the fact that personal health-related information is collected about users through this procedure.

## EVALUATION AND DISCUSSION

To test our design concepts, we worked in partnership with SeniorNet [7]. We began by interviewing Regional Coordinators about accessibility problems of seniors. This produced the expected outcomes in terms of acuity problems, but also revealed other issues. For example, the seniors reported difficulty reading text when displayed against background patterns. Informed input such as this expanded our list of requirements low vision users.

To explain the user experience, we'll give an example of the steps taken by an individual person. A user begins a session by logging in to a UAG site. Registered users then have their profiles available and can continue web usage with no additional constraints. New users must indicate their preferred settings through choices from a series of examples. Once preferences are established, the user may navigate to any web site they wish and the pages will be served up to them with transformations made to accommodate their needs.

Work is now continuing to refine the UAG system in terms of both functionality and usability. With a goal of making the web accessible to users experiencing a variety of disabilities, we currently are exploring ways of adding functionality that will accommodate blind users and users with motor impairments.

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# THE WEBAUDIT AS A SCREENING AND DIAGNOSTIC INSTRUMENT FOR HUMAN REVIEW OF WEBSITES

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## ABSTRACT

The World Wide Web is an increasingly valuable resource for news, communication, education, commerce and entertainment. The design of a website can block or impede access to this information for people with disabilities. The Web Accessibility and Universal Design Information Tool (WebAUDIT) can be used to assess the overall accessibility of websites. It focuses on the evaluation of the user-interface of web pages and the application of universal design concepts in the context of today's browsers and assistive technology. WebAUDIT was created with the expectation that it would not require specialized knowledge of HTML or web design. This paper summarizes the development process and features of this evaluation tool.

## BACKGROUND

As reliance on the Internet for commerce, entertainment, access to employment, education and information grows, equal access to website content can no longer be considered a luxury available to a limited audience. Legislation is being created and strengthened to ensure accessibility. Problems associated with web accessibility may affect as many as 30 million people in the United States alone (1). Individuals with physical, visual, auditory or cognitive disabilities have more difficulty accessing information in websites than individuals without impairments (1). Poorly designed websites can create barriers to using assistive technologies such as screen-readers, text browsers, refreshable Braille and alternative input devices that are often critical to website access for persons with disabilities. This becomes an even more urgent issue when considering the potential that computers and Internet technology have in increasing access to information, work, education and recreation, particularly for persons with a range of disabilities (2).

Many barriers to website accessibility can be eliminated or minimized through the application of user-interface standards and universal design principles that support the use of assistive technologies and the accessibility of web content. Universal design refers to "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design"(3). Accessible web pages benefit all users regardless of disability by also supporting the use of technologies such as web-compatible cell phones and personal digital assistants, and features such as faster downloading times and the use of good design principles. Website evaluation tools such as WebAUDIT (4), can increase awareness of website accessibility issues and can help in the evaluation and improvement of individual sites.

## STATEMENT OF THE PROBLEM AND RATIONALE

There are a limited number of easy to use, comprehensive tools that help in evaluating the accessibility of websites based on the user-interface and application of universal design principles (1). These characteristics do not appear to be within the primary scope of existing web page accessibility evaluation tools, which tend to focus more on HTML and browser compatibility issues affecting accessibility. While some of these evaluation tools also include aspects of the user-interface of web pages and universal design concepts, they do not provide a comprehensive evaluation of these qualities and application to a broader range of disabilities (including cognitive, as well as physical and sensory impairments).

The Web Accessibility and Universal Design Information Tool (WebAUDIT) was developed to help fill this gap. It was created to identify and address common accessibility issues in website design for physical, sensory and cognitive impairments. The WebAUDIT utilizes human review guided by a comprehensive questionnaire and manual to evaluate whether or not an issue is critical to accessing information within a website *(see Appendix A for sample questions)*. WebAUDIT can increase awareness of disability issues and offer suggestions to remedy problems areas through information provided in the questions and in the manual.

## DESIGN AND DEVELOPMENT

WebAUDIT was developed as a tool for standardizing and guiding the subjective evaluation of the accessibility of web pages to individuals with disabilities. It originated from a previously designed tool, the Web Accessibility Questionnaire (WebAQ) (5), created as an undergraduate project by occupational therapy students at the University of Wisconsin-Milwaukee. The project began as an accessibility audit of websites as part of Project IMPACT, a national model demonstration activity to examine accessibility of technology in the campus environment (6). Although WebAQ proved to be significant for identifying web accessibility barriers, it had limitations that affected its usefulness as an evaluation tool.

Recommendations made by the original authors led to the development of the WebAUDIT. Extensive rewrites of the questionnaire and the manual, as well as format changes, led to a more user-friendly, functional version of the instrument that can be used by individuals with a variety of disability and Internet expertise. A greater emphasis was placed on constructing questionnaire items that reflected criteria consistent with universal design principles. The final WebAUDIT questionnaire is composed of two parts. Part 1 is comprised of 20 questions that were determined to be the most critical in evaluating the accessibility of information in a website. At a minimum, these questions should be completed in order to identify any serious problems limiting access for persons with a disability *(see Appendix A for sample questions)*. It is recommended that Part 2 also be completed for the most comprehensive assessment of the accessibility of a website, even though Part 1 can stand alone as a quick evaluation tool or screener. Part 2 contains 51 questions that deal with issues that, while not completely blocking access to information, may present barriers to accessing information. Part 2 is further subdivided into categories of related questions.

The WebAUDIT questionnaire uses a scale *(see Appendix B)* that provides a score representing an overall assessment of how well a website meets the criteria within the questionnaire. Bar graphs are generated using a spreadsheet application and display scoring results. Studies are currently collecting the validation data to quantify the usefulness of the WebAUDIT.

## EVALUATION AND DISCUSSION

In the future, WebAUDIT will need to evolve with changes in web page technology, assistive technology and cultural expectations related to disability. Results from continued testing and user feedback are needed to further evaluate and refine the WebAUDIT.

The WebAUDIT questionnaire in conjunction with the use of the manual provides a user-friendly web accessibility evaluation tool for a variety of skill levels and applications. The WebAUDIT facilitates accessible web design, promotes universal design concepts and provides education on disability awareness and advocacy issues. While WebAUDIT does not take the place of existing web accessibility tools, it goes beyond their scope in that it is unique in providing a method for measuring the quality of the web page user-interface and for adhering to standards of universal design.

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## APPENDIX A: WebAUDIT, Part 1 Sample Questions

(Refer to the scale in Appendix B).

1. Font characteristics, such as size, style, color and spacing, support the readability of the text.
2. Site avoids the use of patterned backgrounds and poorly contrasting content that can make it difficult to read or interpret information.
3. Information is provided in a clear and organized way. For example, headers are used to separate paragraphs or lists, similar contents are grouped together and the site is not overly busy and cluttered.

## APPENDIX B: WebAUDIT Scale

Yes = Indicates that the item under review is present and effective.
Partially (P) = The item under review is only sometimes present and/or effective.
No = The item under review seldom or never meets the criteria specified.
NA = Indicates that an item is not applicable to the website under review.

# MULTIMAIL EMAIL TRAINING FOR COMPUTER USERS WITH DISABILITIES

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ABSTRACT

Comprehensive email training for computer users with disabilities requires careful documentation with full consideration of user characteristics and delivery requirements. A project funded by the Australian government is investigating training issues and solutions in the delivery of the MultiMail email program to computer users with disabilities and to those who support them. This research-in-progress describes a rationale for documentation of training, challenges posed by using different modes of training, and initial results on training preferences from participants in remote areas of Australia.

## BACKGROUND

What is involved in designing and delivering comprehensive Internet training packages for computer users with disabilities? This question has been asked by several 'AccessAbility' grant holders in Australia over the past two years. AccessAbility is an Australian Commonwealth funded program that supports Internet research and development projects with a focus on access for people with disabilities: URL http://www.dca.gov.au/accessability/

Documenting Internet training approaches would be of use to potential trainers and computer users with disabilities. A literature review into training approaches for these computer users has revealed that some information is available but it is usually not presented as a comprehensive program with goals/objectives, learner characteristics, needs assessment, a description of functional access limitations which impact on training, detail of steps involved in training, and evaluation of the efficacy of training. Generic computer training books and book chapters are available that serve as a valuable resource for constructing a training framework which then requires adaptation for computer users with disabilities [4, 1, 2, 6].

The need for accessible training information was identified by the authors early in the development of innovative email software, 'MultiMail.' MultiMail was designed and developed in 1999-2000 with the input of computer users with disabilities and disability agency staff who support them [3, 5]. MultiMail has a range of interface and user options such as switch access with scanning, large print, highlight text, button options, choice of colors, synthesized speech, and word prediction. Spell checking is also included with all interfaces to assist with literacy. The MultiMail interfaces and user options were based on those used with the MultiWeb Internet browser. To reduce the barrier of cost for potential users, MultiMail is available free to download from the Internet: URL www.mis.deakin.edu.au/multiweb/

MultiMail's documentation and Help File information were written in Plain English and carefully task analyzed as this was predicted to be important in a training program. More information was required, however, before a comprehensive training program could be developed that would be presented face-to-face to individuals and groups and to remote users via the Internet. This research-in-progress is investigating issues and solutions toward the development of a MultiMail training package for people with different abilities in urban, rural, and remote areas. These participants will experience different methods of training delivery. In the construction of a generic training package that will be modified for the different groups of users, the following questions have been posed:

- What are the general design and delivery considerations in training people to use the Internet?
- Which Internet training approaches/methods have been found to be effective for people with disabilities?
- How do different access needs impact on the design and delivery of training?
- How can the MultiMail training program be designed so that it can be replicated and its efficacy measured post-training?
- How is the 'online training' for MultiMail different to face-to-face training?

## METHOD

A training package is being developed and will be informed by a literature review, interviews with stakeholders, and survey results from allied health professionals who work in remote areas of Australia. The literature review and training package are due for completion in February, 2001. MultiMail training will be delivered to 18 groups of participants in urban and rural areas of the three eastern states of Australia. Individual training is also anticipated with youth and young adults who have an intellectual disability and with individuals who have physical/sensory access requirements. The Internet will serve as the conduit for training for allied health professionals and educators who work in remote areas of Australia with indigenous people who have disabilities. Participants will complete a survey prior to the training session, then have a period of time to learn/maintain skills, followed by a post-training survey. Assistance will be made available during the training period via email or telephone. Quantitative data from surveys and from email or telephone queries during the project will be analysed descriptively. Depending on the amount of qualitative data that is submitted, N-VIVO software will be utilised for analysis.

## RESULTS

At this point, pre-training survey data from allied health professionals (N=15) who work in remote areas of Australia has been received. These individuals work with indigenous people with disabilities and travel up to 800 kilometers on a twice-monthly basis to see clients. All respondents use the Internet and expressed interest in keeping up to date with new disability-relevant software. Respondents were asked about their preferred methods of receiving training, the amount of time they could devote to learning to use new software, and where they looked for assistance when they needed assistance in learning about the Internet/Email.

Respondents indicated that their preferences for training *when someone was helping them* were (in rank order): demonstration and hands-on, one-to-one demonstration, group demonstration, description of use over the telephone, and learning to use it then demonstrating it to another person. Due to the significant distances between these individuals' work bases and between the trainers and the individuals, it was clear that face-to-face training would be available to them during the project. For this reason, respondents were also asked about their training preferences *when they could read instructions only*. They indicated that their preferred method was a step-by-step approach and simple, get started instructions, followed by (in rank order): fully documented instructions with graphics/pictures, to answer questions that are asked about particular tasks, using multimedia, learning the program then demonstrating it to another person, problem solving using case studies, And reading text-only documentation. The time that they could devote to training themselves to use

## MULTIMAIL TRAINING

MultiMail ranged between 'no time' to 1-2 hours each week. When assistance is required, contact with professional colleagues was the first choice followed by (in rank order): friends, family or book/manual, phone service support and online help support, and discussion with their Internet service provider. Survey results from face-to-face training participants has not yet been collected so cannot be compared with the remote participants. Since individual and group trainees will form the largest group of participants, it is anticipated that they will also indicate a preference for face-to-face training but will need to rely on text and graphics-supported information at work or at home during the training period.

## DISCUSSION

The preferences of trainees, the mode of training delivery, the range of choice of interface and user options offered within the MultiMail software, and the access requirements of computer users with disabilities offer challenges for the design and delivery of training. Remote professionals' desire for personal contact is clear through their preferences for face-to-face training and help from colleagues, friends, and family. When the Internet is used as the communication channel for training, the need for clear, task-analyzed information is reinforced. Surprisingly, respondents did not prefer to learn tasks then demonstrate them to others, a learning approach which has been suggested by Warner (1996) as an effective means of learning when face-to-face training is not possible. By June, 2001, training design features will be documented, pre-training surveys will have been completed, and training for individuals, groups, and Internet participants will have commenced.

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## ACCESSIBILITY OF REHABILITATION WEB PAGES USING JAWS AND BOBBY

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**Abstract**

The INTERNET offers a wealth of information via web sites to people with disabilities (1). Proceeding on the assumption that many blind users rely on a popular screen-reading program, "JAWS For WINDOWS", this study examines the accessibility of a sample containing 30 rehabilitation-related web pages. The ease with which a blind user can navigate around frames and links, access textual content and forms are measured by the JAWS-specific tests that were developed for the purpose of judging the pages. It finds that over 70% of the sample is JAWS-accessible. The study also subjects the web pages to BOBBY-test which reveals that 50% of them are accessible to people with disabilities generally.

**Background**

There are about 2.6 million legally blind persons with no useful vision in the United States. In the past 3 to 4 years, sophisticated screen readers such as Jaws For Windows have offered an effective mechanism to the visually impaired user to access computers and the INTERNET. This has also been helped by Microsoft's promotion of accessibility features that ensure better compatibility between screen readers and applications running on Windows.

Graphically-rich web pages find instant appeal among most sighted individuals. These pages automatically exclude access to blind individuals if adequate text representations of visually aesthetic images are absent. The blind individual is interested in textual content that is accessible and readable by the screen reader. Web pages should load and work when the graphic option on the web browser is turned off. Not only is this the preferred option for a blind individual using a screen reader but it also facilitates quicker loading of the web page. Working with frames in web pages can make keyboard use less efficient to the user of a screen reader as he or she needs to identify them and maneuver into the correct one. Imaginative and meaningful text labels for links that are arranged into logical groups can improve navigation substantially for an unseeing individual using a keyboard. Being able to access web based forms may be important for their independence.

The Authoring Tool Accessibility Guidelines published by the WorldWide Web Consortium's (W3C) Web Accessibility Initiative (WAI) assist developers in designing and producing accessible Web pages (content) and create an accessible interface(2). These have been available for over two years now. The federal government in March 2000 published standards designed to make web sites more accessible to people with disabilities. The requirements for Accessible Software Design support the government's obligation under Section 508 of the Rehabilitation Act of 1973. These guidelines and standards stress the importance of separating content from visual structure and offer practical tips for developing well designed web-pages that may even obviate the need for a "text only" version for blind users.

**Research Question**

Are rehabilitation related web pages accessible to visually impaired individuals using the screen reading program, JAWS For Windows?

**Method**

A search string (+rehabilitation & +disabled & +America & products & services & education employment legal rights assistive technology) was passed through a meta search engine www.cyber411.com. The first thirty rehabilitation related web pages were selected to make up a sample from the web search that identified a set of 227 sites. These belonged to six domains which are COM, EDU, GOV, NET, ORG and US. Sixteen checkpoints that are relevant for judging accessibility of web pages in carrying out common tasks with a screen reader were identified. These related to accessing frames, reading information content, navigating between links and using a web-based form. Sighted assistance was used to carry out three of the 16 tests. These tests aimed to ensure that all aspects of the web page accessible to a sighted user had been accessed using JAWS For Windows. Five web pages selected at random were re-examined to establish intrarater reliability. Following the examination with JAWS, every page was also subjected to the automated BOBBY test developed by the Center For Applied Special Technology. A web page is regarded as accessible if it passes the Priority-1 test; passing Priority 2 and 3 tests is desirable as they signify increased levels of ease in access.

Jaws For Windows (V 3.7) was used in conjunction with Internet Explorer 5.0. The accessibility settings for Internet Explorer were set for use with screen readers that require text display for all images to be turned on, play sound and show video/pictures to be turned off.

**Results**

Table 1: JAWS and BOBBY accessibility of WEB Pages

| Domain | Web Pages Reviewed | Proportion in Sample | JAWS-Accessible Pages | Accessibility Percentage | Bobby Priority-1 | Accessibility Percentage |
|---|---|---|---|---|---|---|
| COM | 7 | 23.33 | 5 | 71.42 | 5 | 71.42 |
| EDU | 8 | 26.66 | 7 | 87.50 | 5 | 62.50 |
| GOV | 2 | 6.66 | 2 | 100.00 | 2 | 100.00 |
| NET | 2 | 6.66 | 1 | 50.00 | 0 | 0.00 |
| ORG | 8 | 26.66 | 4 | 50.00 | 1 | 12.50 |
| US | 3 | 10.00 | 3 | 100.00 | 2 | 66.67 |
| TOTAL | 30 | 100.00 | 22 | 73.33 | 15 | 50.00 |

The study showed that 73.33% of the rehabilitation related sampled web pages are accessible using the JAWS screen reader; factoring in the BOBBY (Priority 1) tests indicate that 50% of the sample is accessible. The intrarater reliability for the testing with JAWS was found to be excellent.

Table 2: Performance of Sampled Web Pages Using Four Criteria With JAWS

| Domain | Web Pages Reviewed | Frames | Text Area | Links | Forms | JAWS-Accessible Pages |
|---|---|---|---|---|---|---|
| COM | 7 | 6 | 7 | 5 | 7 | 5 |
| EDU | 8 | 8 | 8 | 8 | 7 | 7 |
| GOV | 2 | 2 | 2 | 2 | 2 | 2 |
| NET | 2 | 2 | 2 | 1 | 2 | 1 |
| ORG | 8 | 7 | 4 | 6 | 7 | 4 |
| US | 3 | 3 | 3 | 3 | 3 | 3 |
| TOTAL | 30 | 28 | 26 | 25 | 28 | 22 |

*(Figures for web pages that passed the tests include those for which the relevant feature was absent).*

Key Test Findings (See Table 2)

Frames: Out of the current sample, 28 web pages passed the checkpoints under this head. One web page in the ORG domain that had as many as eight frames and one web page in the COM domain presented some challenges in navigation. These sites had no links to non-frame sites. In the COM domain, one page had a single frame <http://members.tripod.com/painrehab>.

Links: 25 pages met the requirements adequately. The others failed the test for reasons that include: using the http address as the display for link, or inability to gain access to links within a frame, labels that said, "Go Here" or used web-site names as prefixes.

Text Representation: The textual contents were readable in all pages including a scrolling title bar on one page. There were a few instances wherein graphic images were not labeled meaningfully and the screen reader would utter some incoherent message. Pictures on some pages had no text descriptors; sighted assistance helped the blind researcher become aware of these.

Forms: 28 sites passed this test. Access to the form was not possible in one instance and the label for a field was not announced in another.

BOBBY Test: Half of the sampled web pages did not reveal any Priority 1 errors. Of those that did, as many as six displayed three or less errors and almost 80% violated the checkpoint requiring alternative text for all images. Five pages in all cleared Priority 2 checkpoints.

**Discussion**

The study indicates a modest accessibility percentage (73%) for rehabilitation web pages for individuals with visual impairment who rely on JAWS for Internet access. (It may be noted that the study excludes visually impaired computer enthusiasts who use other screen readers, or screen magnifiers or web page readers for accessing the Internet) [4][5]. 100% of the pages in the GOV and US domains met both the JAWS and BOBBY tests. Sampled pages in the EDU and COM domains showed better accessibility on both the JAWS and BOBBY tests as compared to the webpages in the ORG domain (see Table 2).

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# Environmental Accommodation (Topic 4)

# MODALITY TRANSLATION SERVICES ON DEMAND – MAKING THE WORLD MORE ACCESSIBLE FOR ALL

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## ABSTRACT

*Two things must occur for a person to use information. The information must be accessible and it must be presented to the person in an understandable way, or mode. This paper introduces the "Modality Translation Services" concept, which comprises a set of remote services to provide instant translation from one presentation mode to another, available anywhere at anytime. This paper will explain these services, potential applications, and show how this concept could benefit people with disabilities and people who are not disabled but experience functional limitations.*

## INTRODUCTION

Thomas Jefferson's words, "Information is the currency of democracy," pertain to today's information society more than ever. Exclusion from information can keep a person from fully participating in society. The problem is not a shortage of information. Indeed, we may often experience information overload. The question is, how can we access information in the way we need (in the appropriate "currency") to be able to use it? For example, it would be inappropriate for a person to visually read e-mail while driving a car because the eyes are busy watching the road and traffic. However, the driver could use a "text-to-speech service" to voice the e-mail messages. Another example is a blind person participating in a business meeting where a diagram is being discussed. Here, an "image description service" could provide a verbal translation for the visual diagram.

## CONCEPT

The "Modality Translation Services" concept is a variety of remote services available anywhere, anytime [1]. These services are becoming possible as a result of recent technological advancements in wide-area, high-bandwidth networks and wireless communication technologies.

### *Service Spectrum*

Modality translation services render information from one specific presentation form (mode) to another. Within the wide spectrum of possible services, each service is tailored to a person's communication needs regarding temporary, or permanent functional limitations (see figure 1).

- *Text-to-Speech* facilitates eyes-free interaction and requires no reading skills for the user. A human reader, or a speech synthesizer, could deliver this service.
- *Speech-to-Text* facilitates real-time ears-free interaction without requiring typing or writing by the user. A human steno-typist, or automatic or human-assisted voice recognition technology, could deliver this service.
- *Speech- to-Sign* facilitates communication between a person speaking and a person who is deaf signing. A human sign interpreter, or a signing avatar (computer-animated character on a display), could deliver this service.
- *Sign-to-Speech* facilitates real-time communication between a deaf person who signs and a non-signing (hearing) person. A human sign interpreter, or an image and sign recognition system, could deliver this service.
- *International Language* translates text, or real-time speech, from one language to another. A human language interpreter, or a machine translation system, could deliver this service.

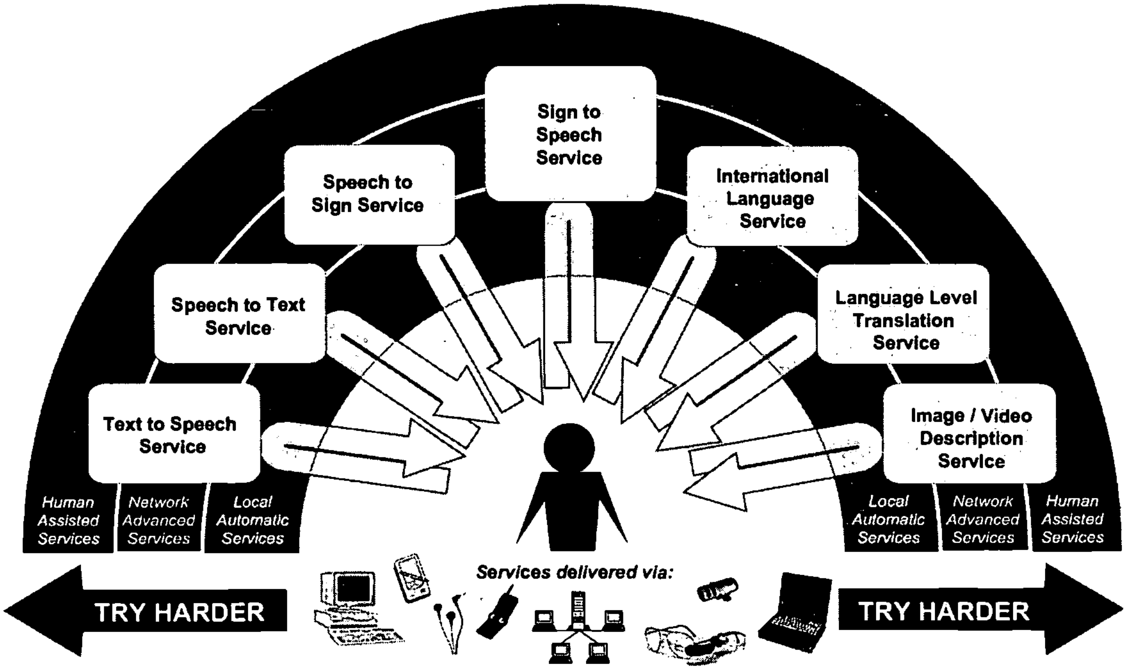


*Figure 1: Modality Translation Service Spectrum*

- *Language Level* simplifies text, or real-time speech, presented in a complex language (cognitive) expertise level. A human interpreter, or an automatic information extraction system, could deliver this service.
- *Image/Video Description* provides speech or text translation from a visual image or video. A human service provider, or an automated system with computer vision, text generation and speech synthesizing capabilities could deliver this service.

### Try Harder Feature

While some of these services can be provided in a fully-automated manner today (e.g. text-to-speech synthesizers for the text to speech service), others may need human assistance for some time (e.g. speech to text, language level translation, and image/video description service). Although more automated services will be implemented with emerging technologies, the early implementations may not be as mature as needed in some cases. In these situations a "Try Harder" feature could be used to harness more powerful applications (network advanced services), and use human assistance in the automatic translation process when technology fails to be effective in certain environments and for certain materials [2].

### Service Access Devices

To use these on-demand translation services, a person needs to have a device that connects remotely to a global, high-bandwidth network and renders information on a display, or through other output units. Although any kind of computer system can be used as an access device, the small, wireless devices bring the real "anywhere at anytime" feature to the user. Examples include handheld computers, cell phones, etc., outfitted with earbuds, buttonhole microphones, or eyeglasses with a built-in monitor.

### *Who are the users?*

We identify four user groups that could benefit from the "Modality Translation Services" concept, differing only in the kind of functional limitation they encounter:

- People with permanent functional limitations such as hearing, visual, and cognitive impairments;
- People with temporary functional limitations like a car driver (cannot use his eyes for reading on a display), a worker in a factory building (cannot hear because of the noisy environment), or a manager in a meeting who needs accurate minutes (cannot type as fast as participants speak);
- People using small (and wireless) Internet devices with restricted input and output capabilities (e.g. handheld computers, or cell phones);
- People facing information given in a different language (having insufficient reading or hearing skills in that language).

## APPLICATIONS

Many of these services are already implemented in a human-assisted, semi-automatic or full-automatic manner. Examples of the speech-to-text service include Ultratec's Instant Captioning™ technology [3] and the Classroom Captioner from Personal Captioning Systems [4]; for the speech-to-sign service the Signing Avatar™ from VCom3D [5]; and for the international language service the AltaVista Babel Fish translation service powered by SYSTRAN [6].

In order to make these services available to a broad user basis they should be embedded in a globally available telecommunication network. As part of the Partnership for Advanced Computational Infrastructure (PACI) [7] the Trace Center is currently investigating options and promoting feasible solutions for modality translation services on the Grid, and other next-generation networks, services and computational resources [8].

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# A Universal Interface for Telecommunication

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## ABSTRACT

A universal interface for telecommunication has been implemented using a PC. This interface is suitable for communication between users with and without motor and sensory disabilities. Users can communicate with each other using one or a combination of text, graphics, speech and video. Single switch users can access the interface using the built-in software scanning keyboard and an ability switch connected to a modified mouse. Access can also be done using one or a combination of keyboard, mouse, touch-screen, and voice. Other input/output devices are possible via the standard I/O ports of the PC. Features of the universal interface are within the capability of but not implemented in present mobile phones and announced 3G phones.

## BACKGROUND

Currently, a person with physical or sensory disability has to rely on modification of existing products or special products tailored to overcome his particular form of disability. Common hi-tech consumer products, although feature rich, have no provision for people with a disability. One good example is the mobile phone. It is a popular consumer product and market forces create fierce competition among the hi-tech manufacturers to provide better and more capable products. On top of routine telephone functions, some mobile phones now include features such as games and voice dialing. The drive for mobile data transmission using mobile phones elevated the bandwidth of these devices from 9.6kbps (GSM) through 14.4kbps (WAP) to the present 115kbps (GRPS). To take advantage of the increasing bandwidth, some latest mobile phones merged the capability of telephones and PDA with a large graphics display and touch screen. However, there is no provision for people with a disability such as an ability switch input and scanning interface for the severely physically handicapped, and a talking menu for the blind. The recent much touted introduction of a neck loop attachment for coupling with hearing aids by a major mobile phone producer for their own line of phones highlights the sorry state of accessibility of mobile phones.

## STATEMENT OF THE PROBLEM

Is it possible to construct a universal interface for telecommunication, including the public telephone network, LAN and the internet, so that people with and without disabilities can communicate with each other interactively in real-time?

## RATIONALE

The two basic tasks for real-time, interactive telecommunications are establishing a communication link and interpersonal communication.

To establish a communication link with a particular person using a PC-based device, a user has to dial a telephone number, or enter an identification code such as an IP address to establish a connection via a telephone network, LAN or Internet. A universal interface has to allow full access to this process for users with or without physical and sensory disabilities.

Once a communication link is established, users will communicate with each other using one or a combination of text, graphics, speech and video. The choice of modes for interpersonal communication depends very much on the ability and disability of communicating parties. A universal interface has to provide modes of communication to allow intelligible interpersonal communication between users of different abilities, such as a deaf-blind person and a person without disability.

For a PC-based device, the following is a non-exhaustive list of features and possible target users for establishing a communication link:

1. regular keypad: person with adequate visual and motor ability (e.g. person without disability, deaf)
2. Braille keypad: blind (i.e. blind, deaf-blind)
3. touch screen and software keypad: person with adequate visual and motor ability (e.g. person without disability, deaf, physically handicapped, person with mild cognitive disability)
4. ability switch and scanning software keypad: severely physically disabled
5. voice dial: person with good voice (e.g. person without disability, blind, physically disabled)

Unlike the task of establishing a communication link, interpersonal communication involves a sender and receiver possibly using different modes of communication. The following is a non-exhaustive list of features and possible target senders and receivers for interpersonal telecommunication.

1. speech: sender with intelligible speech, receiver with adequate hearing (e.g. persons without disability, blind, physically handicapped)
2. video: receiver with adequate vision (e.g. persons without disability to enhance communication using body language, the deaf using lip-reading, sign and body language)
3. text and graphics: sender and receiver with good vision (e.g. persons without disability, deaf)
4. Braille output: blind and deaf-blind sender and receiver

All the above features are within the capability of a PC with appropriate software and peripherals. Since some mobile phones, especially the newer PDA phones, are handheld PC like devices, it is reasonable to assume that they are also technically capable. In terms of universal design, the universal interface should be user friendly to accommodate for mild cognitive impairment, ailing vision and motor ability.

## DESIGN

A sub-notebook PC with built-in touch screen, modem and LAN is used to implement the universal interface for telecommunication. Standard I/O ports of the PC allow attachment of peripherals such as video camera, Braille I/O devices, and card-phone. Single switch input is done via a modified mouse with the left button contacts connected to a 3.5mm socket.

A graphical user interface is implemented using Visual Basic 6. The main menu allows a user to choose input methods and modes for interpersonal communication. In addition to the standard keyboard and mouse, input using voice or software scanning keyboard is possible. The user can choose one or a combination of speech, video, text and graphics for interpersonal communication. A submenu allows a visually handicapped user to specify the background and foreground color of displayed text for optimal legibility. To facilitate access for the visually impaired, all captions will announce its identity using digitized speech. To allow for simultaneous communication using different modalities, the window for telecommunication contains text boxes for text I/O, a small window for video conferencing and a white board for interactive graphics. The two commercial software used are Microsoft Windows NetMeeting for video conferencing, and a voice recognition package for voice input as well as reading out text. Chatting and whiteboard functions are available within NetMeeting but they require multiple menu selections that are not user friendly for some users such as those who rely on single switch access.

Single switch input can be done using either the left mouse button or an external ability switch connected to a modified mouse. Only the numeric buttons of the software scanning keyboard are active during the task of establishing a communication link for better input efficiency. Once the link is established, the whole software keyboard is active.

## EVALUATION AND DEVELOPMENT

As expected, communication between two universal interfaces using text and graphics is acceptable using the public telephone exchange or Internet. However, only LAN provides the bandwidth for smooth video conferencing.

At present, only an English interface is available. Since this city commonly uses two languages and three dialects, an interface using the other language and dialects will be written.

## DISCUSSION

One of the intentions of this project is to demonstrate the feasibility of using present technology to provide full access to telecommunication by all. The universal interface will be introduced to disability groups and related organizations in the hope that it will increase social awareness and demand to prompt manufacturers to consider accessibility issues for mobile phones. The case of the neck loop accessory to provide accessibility for the hearing impaired shows the addition of a simple feature can go a long way. Similarly, the provision of a single switch input and a scanning interface, technically trivial to include with all mobile phones at the product design stage, would allow ready access by the physically disabled. With the PC-like capability of recently introduced mobile phones with PDA functions, all the features of the universal interface should be technically possible to implement, especially at the design stage. It is a fact that the cost of including features at the product design stage is very much lower as compared with retrofitting.

With the coming of wireless telecommunication technology such as Bluetooth, the approach taken in this project will extend utility of a universal interface to all appliances equipped with similar technology. In other words, it is technically possible to have just one universal interface, tailored for the needs of any particular user, to access all appliances.

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# EVALUATING AUTOMATIC SPEECH RECOGNITION AS A CONVERSATIONAL AID FOR PEOPLE WITH HEARING LOSS

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## ABSTRACT

Automatic speech recognition (ASR) systems that can transcribe continuous speech have the potential to improve communication for people with hearing loss. This paper presents partial results of a project examining communication dynamics, system performance, and user satisfaction with ASR used in live conversations between deaf and hearing people.

## BACKGROUND

Automatic speech recognition (ASR) technology has matured to an extent where it may be considered a transcription tool for communication between deaf and hearing people. The purpose of this study is to explore communication dynamics, system performance, and user satisfaction with ASR in unscripted conversations between deaf and hearing people.

We chose one-to-one conversation as the application based in part on the recommendations of Woodcock (1), a deaf industrial engineer who conducted an ergonomic analysis of ASR's application to deaf-hearing communication in varying situations and with conversational partners of varying degrees of intimacy. She concluded that many communication situations would be unsuitable for ASR, but that its use may be amenable in "one-to-one communication between people who are not overly familiar with one another. In these settings, the more formal style of interaction will avoid some of the challenges for ASR, while carrying less of a relationship burden." This type of interaction is typical of the office worksite, where computers are commonplace, and served as our focus.

Our research methods were adapted from studies of video-mediated communication (2) in which both surface linguistic measures and pragmatic analyses were used to explore differences in communication dynamics with the use of a new technology.

## RESEARCH QUESTION

Among the objectives of the study were: To evaluate how accurately ASR transcribes sustained, unscripted conversational speech, and to understand users' attitudes toward this method of communication when compared with other face-to-face methods and technologies.

## METHOD

Data from six pairs of participants were collected. The six hearing subjects (HS) were adults who had social or professional familiarity with deaf and hard of hearing people and knowledge of the Microsoft Windows™ operating system, but no prior experience with ASR. They received two hours of training and practice with Dragon NaturallySpeaking™ 4.01, selected based on a comparative evaluation of accuracy of three commercial systems. This length of training time was chosen as representative of what a co-worker might reasonably be expected to do voluntarily in a workplace situation. In addition to training the system to their speech, HSs learned voice and keyboard correction methods, how to train on specific words, and how to add words to the system's vocabulary. They were taught single-key commands for turning the microphone off and on, and for bringing up a correction dialogue box quickly while using the ASR system.

Six people with severe-profound hearing loss (DS) were paired with the HSs. Five of the DSs had pure tone threshold three-frequency averages in the better ear (BEA) of 90 dB HL or higher, and one reported a BEA in the 70-90 dB HL range. All were accustomed to producing speech for everyday communication. DSs were given a speechreading evaluation (3); scores on combined audiovisual presentation of sentence material ranged from 44% to 97% words correct.

Each pair met twice and sat facing each other across a table. Dragon NaturallySpeaking ran on a Gateway Pentium III 550 MHz computer with 256 MB of RAM, using a Sound Blaster Audio PCI 64D sound card. No other application software was installed. Two monitors were used: A 27" monitor was situated behind and to the left of the hearing person, and a 17" monitor was situated at the hearing person's right, out of sight of the deaf participant. Both could comfortably view a monitor, but only the HS had control of the computer, via keyboard and headset. A trained stenographer using a computer-aided real-time transcription system transcribed both sessions.

In the first session, the pairs engaged in conversation for one hour, composed of six ten-minute segments under conditions listed below. In the second session, participants completed the Map Task (4), a collaborative problem-solving task with a clear goal and a quantitative measure of communicative success, again under varying conditions. After a warm-up session face-to-face without technology, the following communication conditions were presented in pseudo-randomized order:

- Face-to-face with keyboard (the hearing person could type into a word processing program to clarify communication, if desired)
- Face-to-face using the ASR system for transcription of the hearing person's speech
- Face-to-face using the CART system for transcription of speech
- ASR system only (with a barrier between participants, precluding speechreading)
- CART system only (with a barrier between participants, precluding speechreading)

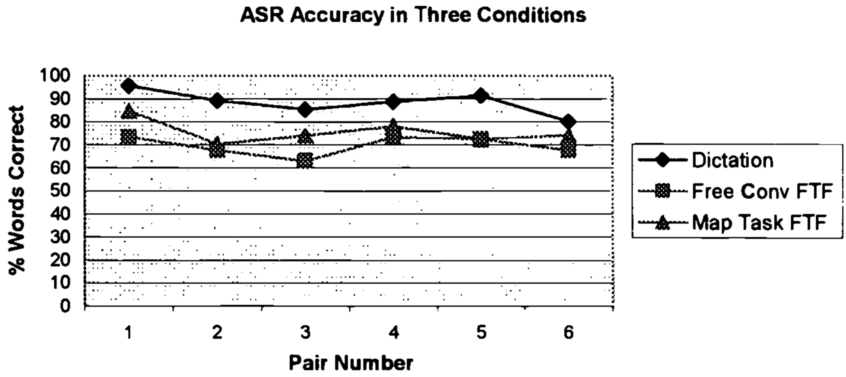
The latter two conditions were included to simulate a remote/telecommunications situation. All conversations were videotaped using split screen and transcribed by the CART reporter. In addition, graphical movies of the ASR output and text files of the ASR, CART, and the keyboard output were made. After each segment, participants completed questionnaires about their opinions of the experience. After both sessions were completed, HSs dictated a 231-word article into the ASR system.

Transcripts of all conversations were amended to include repetitions, fillers, and dysfluencies. ASR transcription accuracy was calculated using a scoring method developed by Stuckless (5), slightly modified for this application; voice commands that were transcribed rather than executed were counted as errors.

## RESULTS AND DISCUSSION

Figure 1 compares ASR accuracy in three conditions: dictation (read text), face-to-face free conversation, and face-to-face communication in a problem-solving task. The demands of face-to-face conversation resulted in an accuracy penalty compared to the dictation condition. The difference between the dictation accuracy and the average accuracy in face-to-face communication over two sessions ranged from 9% to 20%. Improvement between the first and second session was negligible for four cases. Only HS #1 was able to attain above 80% accuracy while conversing, in the second session.

Figure 1




HSs were ambivalent about trying this method of communication again for communicating with a deaf person, giving it the lowest rating of the face-to-face conditions. DSs were more willing than HSs to try ASR again for face-to-face communication, although communication without any use of technology was their preference.

The next stage of analysis is addressing user and system behaviors that contribute to the accuracy penalty for communication, with an eye to optimizing performance and ease of use under realistic conversational conditions, and an analysis of pragmatic linguistic variables that affect speech communication between deaf and hearing people.

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# COMPLETION OF UNIVERSAL DESIGN PERFORMANCE MEASURES

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## ABSTRACT

The authors developed and tested two sets of Universal Design Performance Measures that reflect the Principles of Universal Design. One version is useful for product designers developing new products and the other version for individuals assessing products before purchase. The Measures were tested by a diverse group of 60 consumer households and 18 professional product designers using four common household products.

## BACKGROUND

The authors are conducting a three-year field-initiated project, funded by the National Institute on Disability and Rehabilitation Research (NIDRR), titled "Promoting the Practice of Universal Design." The purpose of the project is to increase the acceptance and adoption of the universal design approach by mainstream product industries. One project task is to develop a method of evaluating products to determine their universal usability; another task is to develop an evaluation service for industry based on this evaluation method. The project began in June 1998 and is scheduled to run through May 2001.

## STATEMENT OF THE PROBLEM

This paper presents the results of the first two and a half years of project work regarding the development of a set of Universal Design Performance Measures that are based on the Principles of Universal Design (1) and are easier to apply. The Performance Measures are intended for use by product designers to guide the development of more universally usable new products and by consumers to assess products, either before purchase or already owned.

## DESIGN

The authors originally had hoped to develop a single set of Universal Design Performance Measures that could be used by consumers as well as designers so both groups would be literally working off the same page. This, however, proved to be inappropriate. Consumers are concerned only with issues that relate to their personal needs, while designers should address the needs of the widest diversity of users concurrently. Each of these constituencies requires its own document.

For this reason, two versions of the Universal Design Performance Measures were developed. The consumer and designer versions of the Survey each comprise a set of 29 statements that correspond to the 29 guidelines associated with the Principles of Universal Design.

## DEVELOPMENT

The initial phases of the process of developing the Universal Design Performance Measures were described in two earlier papers, published in the proceedings of the RESNA '99 and RESNA '00 conferences (3) (4). Five distinct versions of the Performance Measures were drafted and reviewed by 28 consumers with disabilities, 18 professional product designers, and 12 marketing managers from across the United States. These were distilled into two working versions of the Universal Design Performance Measures, one for consumers and one for designers. The two documents were reviewed by five project advisors and pilot-tested by four colleague advisors who suggested changes that were incorporated into the documents used in the testing phase. The final versions of the Measures were reviewed by a professional survey designer for clarity of wording.

EVALUATION

Testing of the Universal Design Performance Measures was conducted with consumer households and professional product designers. Test participants were chosen to be as diverse a group as possible in terms of age, abilities, race, geographic location, and socioeconomic status. In order to assess the true universal usability of the Performance Measures, the consumer group included 60 households, 36 of which contained at least one member with an identifiable disability and 24 of which contained no one with a disability. The designer group included 18 households, some containing individuals with disabilities, representing a range of experience with and attitudes toward universal design.

Each household was sent four common home products: a cordless handheld vacuum cleaner, an alarm clock, a plastic food storage container, and a set of single-serving cereals. Participants were asked to have everyone in the household use each product, as appropriate, and keep a carefully structured journal documenting everyone's use of and comments about the products. After using the products for a few weeks, the test participants were asked to complete four sets of the Universal Design Performance Measures, one for each product. (The consumer households received the consumer version of the Measures and the designer households received the designer version.) Each household was asked to provide some basic demographic information, to describe their past experiences using these types of products, and to evaluate the Performance Measures themselves.

The rate of participating households completing the testing was 79% overall: 83% (50 of 60) for consumer households and 67% (12 of 18) for designers. In order to compare the discrete responses on the Measures to the qualitative comments in the journal, both were converted into numerical scores, as follows:

| Measures Response | Score | Journal Comments | Score |
|---|---|---|---|
| "Strongly Disagree" | 1 | Very Negative | 1 |
| "Disagree" | 2 | Negative | 2 |
| "Neither Agree nor Disagree" | 3 | Neutral | 3 |
| "Agree" | 4 | Positive | 4 |
| "Strongly Agree" | 5 | Very Positive | 5 |

In general, the responses on the two documents tracked well. However, as a group, the product designers who took part in the testing were more critical of each product than were the consumers. This may be because the designers knew how the products could be changed to make them easier to use. The designers may be more demanding of design and may have been less likely to blame themselves for any problems experienced.

During the recruiting phase of the project, staff asked the designer applicants about their previous experience with and knowledge of universal design. This enabled a comparison between designers with different levels of knowledge on their ratings of the usability and usefulness of the Universal Design Performance Measures. While the size of the sample was quite small, the trends were clear: the higher the level of knowledge of universal design, the more useful the designer believed the Performance Measures to be. This finding implies that simply providing designers with a paper tool like this one is not enough to support their effective practice of universal design. The usability and disability issues imbedded in the Performance Measures may not be obvious to the novice user. Additional information may be needed to maximize the utility of the Measures.

## DISCUSSION

Developing a set of performance measures for assessing universal design was not simple but the authors believe the Universal Design Performance Measures were proven to have value. The Performance Measures are useful for identifying potential areas for improvement for a product; for comparing relative strengths of similar products; and for identifying potential strengths of a product such as for marketing purposes.

The Universal Design Performance Measures are limited, however, in several aspects. First, the wording in the Measures is so generic it is sometimes difficult for respondents to interpret the statements. Second, it is important for the respondents to apply the Measures separately to each phase of use of the product, such as reading and opening the package, reading and understanding the instructions, using the product, maintaining the product, etc. Third, the results of this project suggest that the quality of the results achieved applying the Measures may depend on the knowledge base of the respondent. Finally, the Universal Design Performance Measures for Designers require the assessor to *guess* how this might be used by diverse groups of people because, for example, closing your eyes is not the same as being blind. One of the most important truths reinforced by this project is that while suggestive, applying a paper tool such as the Performance Measures is no substitute for consumer testing.

The authors believe that the next generation of the Universal Design Performance Measures should be electronic and multi-layered. While this would increase their complexity, it would also increase their usability. An electronic tool would enable users to select the information they need based on the type of product, the aspect of use under consideration, and their level of knowledge of disability and universal design.

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# PUBLIC OPINION OF UNIVERSAL DESIGN IN HOUSING

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## ABSTRACT

Universal design in housing has emerged as a growing area of concern as the aging population increases, and the housing needs of individuals with varying disabilities continue to be unmet. In this study, visitors participating in the 2000 Parade of Homes Fall Showcase SM presented by the Builders Association of the Twin Cities, Minnesota viewed a residential house built with universal design (UD) features, and were asked to complete a survey about the importance of UD features. The results indicated a majority of the participants thought it was important to incorporate UD features in a home, and would consider including UD features in their current homes and retirement homes. Implications for UD in housing are discussed.

## BACKGROUND

A universally designed home is designed and built with the concept of creating an environment that is usable and accessible by all. The idea for UD in housing grew out of recognition that most features needed by people with disabilities were useful to others, thus justifying inclusion in common practice (1). However, there are no federally-mandated standards or codes to make single-family or other forms of private housing accessible and barrier-free (1). Most architects and contractors are just beginning to recognize that UD in housing is a viable industry. "Universal design in housing applies the principles of UD to all spaces, features, and aspects of houses and creates homes that are usable by and marketable to people of all ages and abilities" (1).

## OBJECTIVE

The objective of the survey was to ascertain the perceptions of the public about a residential house built with UD features, including the level of importance, and considerations for including UD features in their current and future homes.

## METHOD/APPROACH

In its 52nd year, the Parade of Homes SM Twin Cities, Minnesota received 739 entries from builders who entered their most outstanding new model homes. A total of 157 homes were entered and judged by persons in the building industry against a checklist of criteria including excellence in exterior and interior design, construction quality, floor plan design, and value within 30 style and price (of structure only) categories (2). One of the chosen houses was designed and built using UD concepts. The survey consisted of 21 questions. The first 8 questions focused on the importance of the following UD features in the house: (1) lever door handles to make it easier to open doors, (2) easy to reach light switches and raised outlets, (3) an exterior ramp for improved accessibility and mobility, (4) an elevator for ease in moving self and items between floors, (5) devices and modifications to increase kitchen convenience, (6) bathroom features (i.e., roll-in shower, grab bar by the toilet) to increase ease of use, (7) interactive screens to monitor home security from any room in the house, and (8) non-slip limestone floors to increase safety, comfort, and ease of movement. Participants ranked the importance of the UD features using a 4 point Likert scale (4 = very important to 1 = not very important at all). The next question asked participants to rate the overall importance of including UD features viewed in the house in their retirement homes, using a

4 point Likert scale of 4 = very important to 1 = not very important at all. Additional questions (7 total) were rated using a dichotomous scale, and addressed the following factors: (1) consideration of UD features in current homes, (2) presence of similar UD features in current homes, (3) consideration of UD features in future homes, (4) recognition of the accessibility symbol in the Parade of Homes SM program, (5) influence of the accessibility symbol on the decision to visit the house, (6) support of government policies to promote UD features, and (7) perceived increase in resale value for a home with UD features. Next, participants were asked to rate their expectations of UD features in a house displaying the accessibility symbol. This item was rated using a 4 point Likert scale of 4 = much better than expected to 1 = much worse than expected. A scale of 0%, 1-3%, 4-6%, and 7-10% was used to determine perceived increase in total cost for a house with UD features, and willingness of the participants to pay an increased cost to include UD features in their homes. Demographic characteristics consisting of age and gender were also gathered. Of the 10,000 expected visitors, 1,656 completed and returned the survey to an on-site drop box after visiting the universally designed house. Data were analyzed using SPSS. Exploratory data analyses were conducted first, followed by descriptive statistics, including cross tabulations.

**RESULTS**

A typical survey respondent was a female (67%) between the ages of 31-45 (33%) (see Table 1). The UD features in the house rated as most important, in order of magnitude were: (1) kitchen devices and modifications (95%), (2) lever door handles (92%), (3) non-slip limestone floors (92%), (4) bathroom features (89%), (5) an exterior ramp (88%), (6) easy to reach light switches and raised outlets (87%), (7) interactive screens to monitor home security (79%), and (8) an elevator (76%). For all UD features, less than 4% of the respondents rated these features as not important at all. Overall, a greater number of respondents (94%) thought it was important to include UD features in their retirement homes, and no respondents thought UD features should not be included in their retirement homes. Table 2 displays the level of importance of the UD features in the house. Most (77%) of the respondents did not have similar UD features in their current homes. Only 52% would consider including UD features in their current homes, compared to 48% who did not want to include UD features in their current homes. However, 85% would consider including UD features in a future home. Slightly more (51%) respondents noticed the accessibility symbol in the Parade of Homes SM program than those (49%) who did not. For the respondents that noticed the accessibility symbol, 23% reported that it influenced their decision to visit the house. In addition, most (59%) respondents thought the UD features included in the house were much better than they expected for a house displaying the accessibility symbol; whereas 39% thought the UD features were about what they expected to see. The findings also indicated that a greater (61%) number of respondents did not favor government policies to promote UD features. Eighty-one percent reported UD features would increase the resale value of the universally designed house, and more (44%) respondents thought the value of the house would increase by 7-10%, followed by 36% reporting a 4-6% increase. However, only 13% were willing to pay the 7-10% increase in total cost. Forty-two percent of respondents were willing to pay a 4-6% increase, and 37% were willing to pay a 1-3% increase in total cost for a house with UD features. Additionally, for the 48% of the respondents who did not want to include UD features in their current homes, 74% would consider and 26% would not consider including UD features in their future homes. Of the 52% of the respondents that would include UD features in their current homes, 96% would also consider UD features in their future homes. All respondents who did (51%) or did not (49%) notice the accessibility symbol overwhelming responded (98% and 99%, consecutively) that the UD features in the house were better than expected. For the majority of the respondents (85%) considering UD features in their future homes, 41% were willing to pay a 4-6% increase in total cost, followed by 39% who were willing to pay a 1-3% increase, and 16% who were willing to pay a 7-10% increase in total cost for UD features in their future homes.

**Table 1**

| AGE | | GENDER | |
|---|---|---|---|
| 76+ | 1% | Female | 68% |
| 66 - 75 | 5% | Male | 33% |
| 56 - 65 | 16% | | |
| 46 - 55 | 29% | | |
| 31 - 45 | 33% | | |
| 18 - 30 | 15% | | |
| Under 18 | 1% | | |

**Table 2**

| UD FEATURE | VI* | SI* | NI* | NA* |
|---|---|---|---|---|
| Bathroom features | 58% | 31% | 10% | 1% |
| Lever door handles | 54% | 38% | 7% | 1% |
| Raised outlets and light switches | 43% | 44% | 11% | 2% |
| Interactive screens for home security | 32% | 47% | 19% | 2% |
| Kitchen devices and modifications | 59% | 36% | 5% | 0% |
| Elevator | 43% | 33% | 20% | 4% |
| Non-slip limestone floors | 52% | 40% | 8% | 0% |
| Exterior ramp | 54% | 34% | 10% | 2% |
| Overall | 46% | 48% | 6% | 0% |

* **VI** = very important, **SI** = somewhat important, **NI** = not very important, **NA** = not very important at all

## DISCUSSION

Upon completion of the tour, many visitors were eager to make UD features a more permanent aspect of their current and future living environments. However, the results varied for how much respondents were willing to pay for UD features. Although the majority of respondents thought UD features important, they did not perceive a need to have federally supported guidelines to promote UD features. This may indicate the public still perceives UD features as "special" features that are based on individual choice, thus not warranting federal attention or monies to make UD features available to everyone. It is unclear why some respondents' initial expectations were not higher for a house displaying the accessibility symbol. Universally designed homes are appealing to both disabled and non-disabled homebuyers, and do not significantly increase the initial construction cost of a house. Therefore, homebuilders and homebuyers stand to gain tremendously by building accessible and barrier-free homes that eliminate the need for retrofitting or adaptations as the person ages or has special physical needs (e.g., pregnancy, elderly parents, incapacitation, etc.) (3). Marketing strategies must be able to communicate the value and desirability of UD in order to eliminate the negative perceptions that UD is only for "special populations." Overall, the findings of the survey indicated that the public was positive about UD in housing once they experienced it

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# DO YOU REALLY NEED A ROLL-IN SHOWER WHEN A PLAIN OLD SEAT WILL DO?

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## ABSTRACT

A national survey was conducted to determine if changes in the ADA accessibility guidelines for bathing fixtures were needed. Four bathtub alternatives with and without adaptive devices (seats and grab bars) and six showers with and without seats and grab bars were evaluated by almost 1200 individuals with mobility impairments. Almost 60% of the respondents ($p < .001$) rated the typical tub/shower combination as the most difficult fixture to use for both bathing and showering even with grab bars. In contrast, less than 40% had difficulty using any of the bathtubs or showers with seats ($p < .001$), even when the latter had a 3"-4" curb. Some of these findings are due to the large number of respondents who were older adults who used wheeled mobility aids. Many of these individuals could stand to transfer in and out of a tub or shower, but did not have the strength to get up and down from the bottom of the tub, or the stamina to stand during an entire shower. These findings reinforce the need for flexibility and a number of potential alternatives to meet the abilities of different user populations.

## BACKGROUND

A number of researchers (1-3) have argued that accessibility standards are primarily based on the capabilities of nonambulatory young adults, and as such may be inappropriate for people with mobility disabilities resulting from pain, weakness, reduced strength and limited stamina, particularly due to aging. As a result, the recent and projected increases in the number of older people with mobility disabilities over the next 50 years (4-7) suggests that a reevaluation of accessibility requirements, including those for the design of bathing fixtures, is important.

In response to this need, the US Access Board, which promulgates the ADA Accessibility Guidelines, sponsored a national survey as an initial step in assessing current guidelines for transfer mobility in common bathing fixtures. The specific objectives of the survey were to identify where gaps existed in design specifications and to suggest where further research was needed to fill those gaps.

## RESEARCH QUESTIONS

1. Do current ADA Accessibility Guidelines for bathtub and shower transfers meet the needs of people with mobility impairments?
2. Are there other typical bathtub and shower designs that are easier for people with mobility impairments to transfer into and out of, than the ones specified in ADAAG?
3. Are there specific issues that can be identified for future research?

## METHOD

A survey was mailed to a nationwide sample of 4100 people with mobility impairments who were randomly selected from a large commercial database. The survey included background information about the individual (age, gender, and disability) as well as information about use of tubs and showers. Questions related to six commonly used shower/grab bar configurations: 1. a shower in a typical bathtub; 2. a typical shower stall with a 3" - 4" high curb; 3. a shower stall with a folding seat; 4. a roll-in shower with a side transfer seat; 5. a roll-in shower without a transfer seat; and 6. a roll-in shower with a rear transfer seat). In addition, four bathtub/grab bar configurations were included: 1. a typical tub; 2. a tub with a movable shower chair; 3. a tub with a movable in-tub seat; and 4. a tub with a rear built-in transfer seat).

## RESULTS

Approximately 60% of the sample was either ambulatory or semiamblulatory. In addition, three out every four respondents (74.3%) reported being able to lift their leg over the curb of a shower. This represents significantly high percentages of both ambulatory individuals and wheelchair users, including 84.2% of the former, and 61.6% of the latter. Not surprisingly, therefore, few respondents (slightly less than 11%) had roll-in showers or used special wheelchairs in the shower. In contrast, almost 2 out of every 3 respondents preferred using bathing and shower fixtures with a seat.

The typical tub/shower combination with grab bars was rated as the most difficult fixture to use to either bathe or shower by almost 60% of the respondents, while almost half of respondents had difficulty using the standard tub with a rear transfer bench ($p < .001$). In contrast, significantly fewer respondents had difficulty with the two fixtures with adaptive in-tub seats ($p < .001$). As expected, roll-in showers presented less difficulty than did standard shower stalls. However, a larger percentage of respondents had difficulty using a roll-in shower without a seat than a shower stall with a seat ($p < .001$), even when the latter had a 3"-4" curb.

Overall, respondents had less difficulty using showers than bathtubs. However, they had less difficulty using fixtures with a seat than those without a seat ($p < .001$). In fact, larger percentages of the respondents reported that showers without seats, including the roll-in shower without a seat (41%), were more difficult to use than the either of the two bathtubs with seats (approximately 40% each). These findings were consistent across users of both wheeled mobility and walking aids. Some of these findings are due to the large number of respondents who were older adults who used wheeled mobility aids. Many of these individuals could stand to transfer in and out of a tub or shower, but did not have the strength to get up and down from the bottom of the tub, or the stamina to stand during an entire shower. These findings reinforce the need for flexibility and a number of potential alternatives to meet the abilities of different user populations.

## DISCUSSION

These findings suggest that bathing fixtures intended for people who transfer directly from a wheelchair to a tub or shower or who use a shower commode chair may not be applicable for older individuals who are semiambulatory. In fact, data from this study suggest that older people need in-fixture seats not because they cannot stand, but because they have difficulty standing for extended periods of time or because getting up and down from the bottom of the tub is extremely taxing. Therefore, fixtures such as roll-in showers without seats that meet current accessibility guidelines or are commonly used in residential design to provide accessibility may not be as effective for older people as fixtures with seats, even when the latter do not meet accessibility guidelines. These findings reinforce the importance of individualizing home environments to meet the needs of older individuals whenever possible.

Do you need a roll-in shower

This study reinforces the importance of individualizing home environments to meet the needs of older individuals whenever possible. When ADA guidelines are not mandated, such as in an individual's own home, it is extremely important that providers of aging services are aware of alternative shower and bathtub configurations and recommend designs that meet the needs of the older resident(s). When ADA accessibility are mandated, such as in long term and healthcare facilities, it is important that design specifications be flexible to facilitate use by individuals with a wide range of abilities.

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## TRAILWARE: TECHNOLOGY FOR THE UNIVERSAL DESIGN OF OUTDOOR ENVIRONMENTS

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### ABSTRACT

Creating outdoor environments that are universally designed is a challenge that must balance the need for access with protection of the natural environment. This project is developing computer software (TrailWare) that can be used to analyze and summarize objective measurements of outdoor environment conditions. The resulting information can be used to design or modify the environment to maximize accessibility while preserving the outdoor experience and environment. The information also can be used to accurately convey objective information about trails to users of all abilities.

### BACKGROUND

The U.S. Architectural and Transportation Barriers Compliance Board (Access Board) develops the Americans with Disabilities Act Accessibility Guidelines (ADAAG) that provide design specifications for newly constructed or alterations of existing facilities required to be accessible through the Americans with Disabilities Act (ADA). Although the ADA mandates that outdoor environments be accessible, current ADAAG cannot be directly applied. For example, ADAAG requires a maximum cross slope of 1:50 (2%), but how can that be achieved or maintained on a natural surface, such as soil? In 1998, the Access Board convened a Regulatory Negotiation Committee (RNC), comprised of key stakeholders, to address this issue. The RNC report will be used to determine guidelines for outdoor developed areas and currently is available for public comment (1).

### STATEMENT OF THE PROBLEM

The RNC report provides proposed accessibility guidelines for the design, construction, and re-construction of outdoor developed areas but does not specify how compliance with the guidelines will be determined. For example, the proposed guideline for maximum cross slope is 1:20 (5%) but the method for measuring cross slope is not specified (e.g., width of area being measured or frequency of measurements).

### RATIONALE

TrailWare is being developed to analyze the data collected through the Universal Trail Assessment Process (UTAP). The UTAP is a measurement system that objectively documents trail characteristics that may affect user access, such as grade, cross slope, surface firmness, width, and the presence of obstacles (2). Research has shown that the UTAP provides valid and repeatable measures of the conditions in outdoor environments (3). However the UTAP measurements are completed over short sections of trail, less than 100 feet in length, which have consistent characteristics. The proposed guidelines provide only for an entire trail segment, from one access point to the next. Therefore, in order to utilize the UTAP to determine the accessibility of a trail, a method of analyzing and combining the data for multiple trail segments was required.

## DESIGN

Research indicates that land managers and trail users have very different needs for trail information and yet both have needs within two areas: environmental protection and access for users (3). Land managers must protect the integrity of the natural environment while allowing use of the environment by the general public. Trail users require access for a variety of activities but also desire to enjoy the activity within a particular type of environment. The optimal method for addressing the needs of both groups is a universally designed system that can be used by all stakeholders to address issues related to both environmental protection and user access.

The primary goal of the TrailWare project is to develop one assessment and analysis system that can be used to meet the needs of all stakeholders, both land managers and users with and without disabilities. TrailWare is being designed to provide a wide variety of benefits, which include (a) determining whether a specific trail or trail segment complies with the proposed accessibility guidelines for outdoor developed areas, (b) providing trail users with objective information about the on-trail conditions to enhance user safety and satisfaction, (c) designing accessible new environments and modifications to existing environments, and (d) enabling land managers to effectively monitor changes in environmental conditions and the impact of human activities (e.g., use, construction, maintenance) on outdoor, natural areas.

TrailWare is designed as a "stand alone" software package that can be integrated with existing computer systems. Data collected using the UTAP can be entered directly into TrailWare, or may be imported from other data management programs (e.g., spreadsheet, database).

## DEVELOPMENT

TrailWare is being created through the use of an iterative design process. Representatives of land management agencies, trail groups, and organizations representing people with disabilities are evaluating beta versions. Focus groups are being used to collectively provide feedback on module development and functionality. Upon completion of the project, TrailWare will become a commercially available product with technical support and upgrades.

A pilot project developed a working prototype of the TrailWare software that utilized a series of custom calculations within standard spreadsheet software. The pilot project demonstrated the feasibility of the TrailWare software concept and was used to establish the goals and objectives for the current project. Research with land managers and trail users with and without disabilities established the effectiveness of the summary trail data from the pilot project software in conveying information about the on-trail conditions. Land managers were able to use the information to determine the need for construction, maintenance and environmental protection activities. Trail users found that they could use the objective information to make informed decisions about whether a particular trail suited their interests, abilities and expertise.

## EVALUATION

TrailWare beta versions were evaluated through a two-phase process to identify strengths and limitations of each version. Initially, the TrailWare project development team tested beta versions to ensure that all features and calculations were functioning correctly. TrailWare was then distributed to trail management agencies and organizations, as well as, trail designers for more in-depth evaluation. Evaluators involved represent (a) six Federal land management agencies and programs,

(b) eight State land management agencies, (c) seven local land management agencies, (d) six organizations that manage trails or serve people with disabilities, and (e) four private trail contractors. The in-depth evaluation focused primarily on whether the functions provided would enable all stakeholders to utilize the software effectively and efficiently to meet their needs for analyzing data for maintenance and design requirements and also for disseminating data to trail users.

## DISCUSSION

For most land management agencies, protection of the natural environment is the highest priority. The ability of individuals to use that environment for recreational activities is generally considered a secondary priority unless the qualities of the environment are maintained there will no longer be a reason or desire for access. Given these priorities, and the mandate for accessibility to natural environments provided by the ADA, attempts to enhance the accessibility of outdoor environments for people with disabilities must also focus on protection of the natural environment.

The TrailWare project will develop one system that can be used to address environmental protection and monitoring as well as user access to the environment. The system relies on objective measurements of the actual, on-trail conditions that are collected according to the methods of the UTAP. These objective measurements accurately describe the trail conditions so that:

1. Land managers can determine what actions may be required.
2. Users can determine the accessibility or suitability of the environment.
3. The decisions of both groups are based on objective information rather than subjective opinions.

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# A MACHINERY MODIFICATIONS CATALOGUE IN CD FORMAT FOR FARMERS WITH DISABILITIES

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## ABSTRACT

The Saskatchewan Abilities Council and members of the Council's Farmers with Disabilities Program worked together to develop the Machinery Modifications Catalogue available to all farmers and health care professionals to promote farming after a disabling situation. This catalogue has been distributed world-wide since its inception in 1988, but new technologies have encouraged further development both in the modifications within the catalogue and the catalogue itself. We developed a CD version of this catalogue that can be used on any computer with a Windows operating system. This method allows computer searches, as well as improved graphics that better describe the modifications.

## BACKGROUND

Since 1985, the Saskatchewan Abilities Council has provided support across Canada for farmers with disabilities and their families through the Farmers with Disabilities Program. The purpose of the program is to ensure that farmers who sustain disabling accidents or diseases are given every opportunity to continue farming, if that is their choice. With peer support, counselling, information on machinery and worksite modifications, adaptive technology and safety, many farmers with disabilities are able to resume their farming careers and continue as productive members of their communities.

The priority of this service is to provide practical information and ongoing support to farmers who have been disabled by accident or illness, along with their families. That information includes ideas for equipment modifications, special tools and farming aids that can help the farmer to work as independently as possible.

The machinery modifications catalogue was initially produced in print in 1988 (1) and is a compilation of modifications, tools and aids used, and often designed by, farmers with disabilities. This resource was intended both for farmers and for healthcare professionals. The modifications have often been custom designed to suit specific needs. Other modifications have been combined to fit a variety of machines, work sites and purposes.

## OBJECTIVE

Although over 250 copies of this catalogue have been distributed, there are several disadvantages of the catalogue in its present form. Updated information has not been added since the introduction of the catalogue in 1988. Also, since the catalogue contains over 500 pages of information, shipping and handling costs are remarkably high. Finally, the layout is by disability rather than by modification type. Although this is useful for some, others find that it is difficult to search for specific modifications. The objective of this particular project was to make the Machinery Modifications Catalogue more accessible and easier to use by both farmers and health care professionals.

## DISCUSSION OF APPROACH

We chose to make the catalogue available in CD format. A CD format allows for continuous updating of information, low cost transmission (internet or CD mail out), and can allow for searching both by modification type and by disability. Another added advantage is that the pictures are in colour to allow for better contrast while describing the new technology.

The first step was to place all the information about machinery modifications that had been collected in the past in computer format. To this point, it had only been available in printed format. Colour photographs were added to the text, allowing a visual interpretation of the adaptation. Although these photographs had been embedded in the original version, it was often difficult to decipher the black and white photocopies. To allow for use on all computers, the files were produced in html format. The following layout was followed to allow for ease of use:

Title Page: Allows the user to enter a table of contents by either Disability or Equipment Type. Users can look for modifications that suit those with a specific disability, or search for all modifications to a particular piece of machinery. Stoller *et al.* from The Breaking New Ground Research Center (Purdue University) is compiling modifications from farmers in the United States in a similar manner (2). They chose to categorise the modifications by work site activity with a sub-category of disability type. We examined this approach and chose to categorise by both, giving the user the option to choose between them.

Modifications by Disability: These modifications are arranged based on disability. Within each disability category, the farmers are listed, as well as each modification that they have developed or use. The categories are as follows: amputees (arm and leg), spinal injured (paraplegic, quadriplegic), illness (polio, nerve-muscle), decreased strength. Control items, commercial items (tools, daily living aids, recreation), and safety tips of interest to farmers with or without disabilities are also linked to this page.

Modifications by Equipment Type: These modifications are based on equipment type, or a particular set of activities: activities in the home, all terrain vehicles, augers, combines, entertainment, farm activities, front end loaders, grain trucks, lifts, safety, tractors, and transportation.

Each modification in the catalogue includes the following information related to each modification:

1. A clear description, usually accompanied with photographs or hand drawn illustrations about the device
2. A description of the method of operation of the modification.

Additional information may also be obtained from the farmer who developed or uses the specific modification. The names and addresses of farmers who use these modifications are also included to facilitate communication between the user and the interested party. Some of the farmers who have developed various machinery modifications suggest that the interested party test the particular modification before spending the time, money and effort to build one themselves. This will also allow them to understand and improve the current design.

## EVALUATION

The Saskatchewan Abilities Council has a "Farmers with Disabilities Advisory Committee "consisting of farmer's with disabilities, an occupational therapist and a doctor. This committee evaluates all activities of the Farmers with Disabilities program. The CD has been reviewed by this group and suggestions by them have been incorporated into the CD. Many of these farmers have contributed to the catalogue and are excited about the new improvements.

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# ELECTRONIC AIDS TO DAILY LIVING, AN ASSESSMENT PROTOCOL

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## ABSTRACT

Electronic Aids to Daily Living (EADL) enable people with disabilities to perform such tasks as use the telephone, open a door or activate the TV. The EADL assessment Protocol, which is guided by the Canadian Model of Occupational Performance (CMOP), helps clinicians to identify and prorize clients' performance issues, performance components, environmental issues and equipment considerations. Trials have shown that use of the Protocol increases clinicians' knowledge of EADL and assists the prescription of equipment.

## BACKGROUND

It has been shown that EADL have a positive impact on quality of life and sense of autonomy (1) for people with disabilities. However, it is also clear that assistive devices are abandoned at an alarming rate (2) (3) (4). The concept of the EADL Assessment Protocol resulted from the experiences of clinicians at Independence Technologies who specialize in EADL service delivery. They recognized the utility of EADL but could not find appropriate assessment tools. In addition, they saw clients who had had inappropriate equipment prescribed in the past and they were receiving numerous inquiries from clinicians who were unsure how to evaluate or address their clients' EADL needs. The development and trial of the Protocol was a fieldwork project for an occupational therapy student from McMaster University, Hamilton, Ontario.

## METHODS/APPROACH

To facilitate the best possible match between the client and the EADL, the clinician works with the person, clarifying issues, gathering information and making recommendations. This information-gathering step has traditionally been called "assessment". The Canadian Model of Occupational Performance (CMOP) reframes assessment in a more comprehensive way. The CMOP is outlined in "Enabling Occupation" a recent document from the Canadian Association of Occupational Therapists (5). The Protocol follows the CMOP while focusing on issues specific to EADL.

The first and most important step in this process is the identification of things the client wants or needs to do. This step is called "Identifying and Prioritizing Occupational Performance Issues", and can be accomplished through the administration of the Canadian Occupational Performance Measure (6). Tasks and activities which the client identifies as important should remain the focus of the intervention process. Supplementary COPM questions, which encourage consideration of EADL issues, are included in the Protocol.

The second step in the CMOP process is called "Determining a theoretical approach", and suggests that the clinician consider the contributing causes of the client's issues or problems. These causes are then the basis for decisions made throughout the rest of the intervention, including what else to assess, and how to proceed with intervention. For example, a client may be unable to use a standard telephone handset because of muscle weakness, secondary to multiple sclerosis. The clinician would proceed knowing the client has a neuro-degenerative disease, in which function may deteriorate over time.

The next step is "Determining Client Performance Components and Environmental Conditions". The EADL Protocol borrows from the CMOP framework to organize data collection. Performance Components have to do with the person, while Environmental Conditions are external to the person. This is probably familiar territory for many clinicians. Muscle strength, joint range of motion, client cognition and emotional status are measured. Additionally, the clinician looks at the environment: the person's home, or place of work, for example. One considers issues such as integrating other equipment, and cooperating with caregivers. In assessing the client's performance components, significant attention is given to EADL "access", or the interface between person and device.

The last section of the Protocol addresses general equipment considerations such as safety, installation, and warranty issues. It then addresses specific equipment issues e.g. "Does the client need to dial a prefix in order to make a telephone call?" or "How many televisions does the client want to control and in which locations?"

Evaluation of the Protocol was made in two steps. Initially, 24 clinicians in Canada and the United States were asked to look at the Protocol and provide informal feedback. Feedback was generally positive and after some minor modifications a formal trial was initiated.

Twenty occupational therapists were chosen randomly from the database at Independence Technologies and asked to take part in the formal trial. Prior to seeing the Protocol, they were asked to complete a pre-questionnaire to ascertain their background experience and perceived knowledge of EADL. They were then asked to use the Protocol with at least one client and complete a progress questionnaire which indicated the sections of the Protocol used and their utility. Following the trial a post questionnaire was completed to measure if perceived knowledge had increased. Fourteen therapists agreed to take part in the trial. Ten completed the trial.

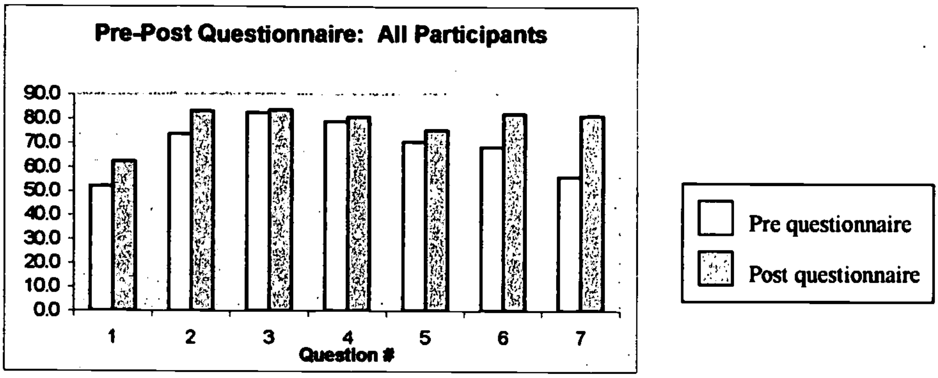
## RESULTS/DISCUSSION

The participants in the study had a broad range of experience. Of the clinicians who completed the trial, six were considered specialists in assistive technology and four were considered non-specialists. 4 clinicians assessed more than one client. All the dropouts in the trial were non-specialists.

The progress questionnaire showed that 71% of times clinicians used the "EADL Information Sheet" as a basis for discussion with their clients. Only 50% used the COPM but it may have been used and not formally scored. 71% of clinicians decided to complete the intervention on their own, while 29% decided to refer to a specialist in EADL. The length of the trial did not allow for completion of prescription and re-evaluation of client satisfaction. This requires further follow up.

The results of the pre and post questionnaires are shown below.

| Pre and Post Questionnaire Responses (scored out of 100) | Pre | Post |
|---|---|---|
| 1. Rate your knowledge of EADLs. | 51.9 | 62.3 |
| 2. Would you accept a client whose needs suggest using EADL? | 73.4 | 82.9 |
| 3. Rate your comfort with describing assistive devices of any kind. | 82.3 | 83.5 |
| 4. How comfortable are you in using the COPM assessment? | 69.9 | 74.9 |
| 5. Rate your ability to assist clients in identifying their EADL needs. | 67.9 | 81.7 |
| 6. Rate your comfort with prescribing basic EADL. | 55.5 | 80.8 |




Overall, the trials showed that use of the EADL Protocol increased knowledge in EADL and increased comfort with prescription. A longer evaluation is needed to determine if clients were satisfied with the prescriptions.

Those non-specialists who completed the trial reported anecdotally that they found the topic of EADL intimidating but they believed that continued use of the Protocol would increase their knowledge and comfort level.

The authors are currently seeking a publisher so that the Protocol will be readily available.

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## CREATION OF A WEB DATABASE FOR JOB INFORMATION

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### ABSTRACT

Objective job information can assist professionals in making job accommodation and return to work decisions. A web-based database has been created as a means of collecting and disseminating job information. Examples are presented of how professionals can use the database when making job accommodation and return to work decisions.

### BACKGROUND

People are often excluded from certain jobs because job demands are perceived as "excessive." In some cases these perceptions are based on objective job analyses but in other cases they are based on stereotypes. Stereotypes are unreliable and potentially discriminatory, for example keyboard work can vary from a transcriptionist who has a very high hand activity level to a receptionist who very infrequently types on the computer. Ideally objective job analysis information is available but in some cases it isn't due to limited worksite access and limited resources to analyze multiple jobs.

One solution is to construct a database of jobs. In some cases the database will have an exact match to a worker's job. The rehabilitation professional can directly use the job information to make decisions. In the other case, examples can be found that enable the health care provider and worker to generalize from a know reference point by discussing the similarities and differences of the database job to the worker's job. Similar jobs can be compared and contrasted to determine the "best" way to do a job. The job database illustrates the variations in jobs to avoid over generalization. Knowing job demands can assist in the development of "functional" worker assessments and the evaluation of interventions.

### STATEMENT OF PROBLEM

A method is needed to disseminate objective job information to the wide variety of professionals making worker/job decisions (including doctors, rehabilitation counselors, employers and employees.) Figure 1 shows the variety of information from the many sources that the database needs to store. The dissemination method needs to interface with parallel efforts to document worker abilities and interventions. "Intelligent" agents, being developed to determine potential gaps between job demands and worker abilities and suggest interventions to eliminate these gaps, also need access to the job information.

| | Job Information | Collection Methods | Ergonomic Assessment |
|---|---|---|---|
| Least Precise & Accurate ↓ | Industry Names | Phone Interviews | Industry Statistics |
| | Occupational Titles | Records | High/Low Classification (Based on Job Title) |
| | Job Titles | Observations | Rating of Individual Risk Factors |
| | Tasks Descriptions | - Site Visit | - High/Med/Low |
| | Elements list/descriptions | - Physical Measurements | - 10 point scale |
| | Postures, Motions & Forces | - Still Photos | NIOSH Lifting Equation and other quantitative evaluations |
| Most Precise & Accurate | | - Videos | Joint load computations |
| | | Instrumentation | |

Figure 1: Information sources and levels of precision to be stored in the database.

## DESIGN

A web-based interface was chosen as a means of collecting and disseminating the job information. Underlying the web interface is a relational database containing the job information. Use of a relational database allows for efficient storage and organization of job information. Relational databases allow information to be stored in linked tables minimizing redundancy and increasing storage efficiency. Figure 2a shows a very high level overview of the tables in the job database.

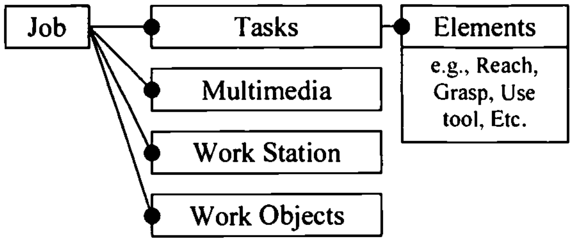

Figure 2a: High-level organization of tables in job database

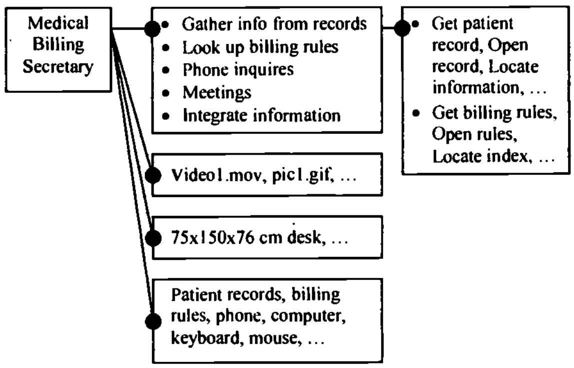

Figure 2b: Example of job as stored in job database

Using the web as the interface to the database allows access from a variety of locations. Web pages can be designed to allow individuals with all types of disabilities to easily access information. Dynamically generated web pages allow instant access to the latest information and for the web server to provide pages appropriate to the connection speed of the user (1). They also allow the information to be customized for the viewer. Additional information is accessible via links but the information is not downloaded until requested, thus speeding up initial download times.

## DEVELOPMENT & EVALUATION

The user interface for the database is a web site (1) that is dynamically generated as active server pages. To increase browser compatibility and accessibility, scripting is done on the server side. To enable access by those using screen readers or text-based browsers, alternatives are available for tables and text descriptions are being provided for all graphs, pictures, and movies. The site is being automatically checked for accessibility in addition to manual testing by a variety of users with and without disabilities. Significant difficulties were encountered when testing the mpeg movie format with different browsers. The solution was to convert all of the videos to Apple's QuickTime movie format. The size of the video files was significantly reduced using compression techniques to facilitate viewing over modem connections. Formal usability testing is being planned to study the effectiveness and usefulness of the interface.

## DISCUSSION

To add even more functionality and usefulness to the web site, the job database can be integrated with worker ability and intervention databases creating several new scenarios of how the information in the job database will be used. One scenario (depicted in figure 3) takes a job and combines it with a variety of interventions creating a whole family of new jobs. These new jobs can then be evaluated for potential or current employees. For example there might be an opening in the medical billing position described in Figure 2b. The medical billing job, which requires moderate computer entry, can be combined with speech recognition technology, a trackball, and/or an adaptive keyboard. Objective job information helps identify the essential job functions while the interventions help open employers minds to reasonable accommodations that are available but may not previously have been considered. Employers will be able to compare more candidates for the job, including individuals with repetitive stress injuries or physical disabilities who may otherwise not been considered due to perceived job demands. A second scenario for using the information (depicted in figure 4) takes a worker and a job and tries to identify any gaps between the job demands and the worker abilities. These gaps can then be eliminated using items in the intervention database leading to one or more accessible job options that match a particular worker's abilities. For example it would be possible to identify some of the gaps between the capacity of a worker with back pain and the demands of the medical billing job. Gaps can be identified including long periods of sitting at a desk and forward bending to examine patient charts. It can be seen that a document stand, using a sit-stand workstation, and/or a reclining workstation would help overcome these barriers to employment. While the database helps to identify gaps and provide insights for interventions, a rehabilitation engineer, therapist and feedback from the health care provider and worker are still required for implementation and evaluation. Qualities, abilities, and motivations vary considerably from person to person. It is important that each person be given every opportunity and the benefit of the doubt. The database and computer tools described should be viewed as a tool to facilitate the efforts of the rehabilitation team.

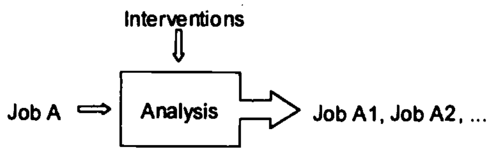


Fig 3: Analysis of both job documentation and potential interventions leads to new or modified jobs that fulfill the same role as the original job

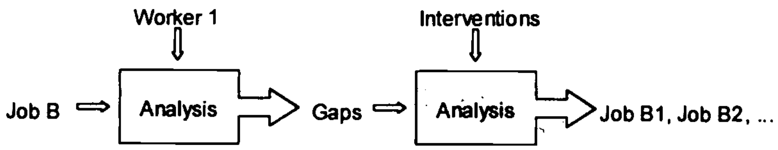


Fig 4: A worker's abilities are compared with job requirements leading to the identification of gaps. These gaps are eliminated using interventions leading to jobs that are accessible to the worker.

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# EXAMPLES OF ERGONOMIC INTERVENTIONS IN MANUFACTURING AND OFFICE ENVIRONMENTS

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## ABSTRACT

Musculoskeletal disorders are a major financial cost to industry and personal cost to workers. Ergonomic job analysis and subsequent workplace changes often occur after workers report discomfort, pain or injury. Examples of ergonomic job analysis and workplace changes for workstations from both manufacturing and office environments are described. Risk factors associated with the development of musculoskeletal disorders were reduced after the workplace changes were introduced. In addition, worker discomfort was also reduced.

## OBJECTIVE

Both ergonomic job analysis and implementation of interventions are often used by employers to reduce identified work-related risk factors and work-related discomfort and injuries. The objective of this study was to document worker injuries, document work tasks, tools and equipment, complete an ergonomic assessment, and provide recommendations for workplace interventions. After comparing the job requirements and worker abilities, gaps between the two were identified. Recommendations were then developed to eliminate the gaps so the worker could perform the job.

## METHOD

During the visit to the work site, workplace documentation was collected. The documentation included worker injury history, sketch of work area, description of work objective, tasks, work equipment, tools, materials, environment, and work schedule. In addition, real-time videotape of the worker performing the job was taken. The manufacturing job that was studied, O-Ring Installation, was a cyclic assembly line operation. However, the office job, Academic Advisor, was not cyclic and was classified as professional / managerial. Consequently, real-time and time-lapse videotape were used. Time-lapse videotape of work tasks was used to capture the percent of the work day the Academic Advisor spent doing different work activities.

Next an ergonomic assessment of the risk factors related to musculoskeletal disorders was completed using a methodology developed by Latko, et al. (1997). 10-point scales were used to rate the risk factors where 0 = very low level of exposure and 10 = very high exposure. The ergonomic risk factors that were rated included repetition, force, posture and localized contact stress. After review of the ergonomic assessment, intervention recommendations were developed to address the identified risk factors. Implementation of the workplace changes were the responsibility of the employer and were made in consultation with the worker and/or worker representatives. Each job was evaluated again after the workplace changes were implemented.

## RESULTS AND DISCUSSION

<u>Case 1: O-Ring Installation, Manufacturing Job</u>

A 35-year old male developed a right shoulder injury while working on O-Ring Installation. This job consisted of a seated workstation with 150-160 units completed per hour. The work tasks included: 1) rotate assembly, 2) get and place o-ring, 3) build-up sub-assembly, 4) place sub-assembly into transmission. Table 1 contains the ergonomic assessment and Figure 1 depicts the job. Overall, this was a medium repetition job that required high force exertions to rotate the transmission assembly, localized contact stress between the fingers/hand/palm and the parts, and awkward postures of the wrist, forearm, shoulder, neck and back throughout the work cycle. Gaps between the worker's functional abilities and required tasks were identified. These gaps included 1) force required to rotate the assembly, 2) reach behind the body to get parts, 3) extended forward reach to place o-ring in the transmission assembly and 4) wrist flexion/extension to reach parts and to rotate the assembly.

The workplace changes included automation to rotate the transmission assembly, revised layout for stock and elimination of the sub-assembly. The repetition of the job, forceful exertions, localized contact stress and awkward postures were all reduced (see Table 1 and Figure 2). There has been no reported worker discomfort or injury since these interventions were implemented.

Case 2: Academic Advisor, Office Job

A 51-year old female developed low back pain that sometimes radiated down the legs subsequent to a fall. Her work equipment consisted of a seated workstation in an office with a computer, desk, conference table, shelves, file cabinets, footrest, wrist rest, phone and an adjustable chair. She had a variety of work tasks that were categorized in the following manner: 1) attend/conduct meetings (in-person and via the phone), 2) computer work (e-mail, database development, budgets, planning) and 3) paper work (review records, reconcile purchases). Table 1 contains the ergonomic assessment and Figure 3 depicts the job. Overall, this job contained low levels of repetition, force and contact stress. Moderate levels of posture stress were observed. Constant sitting was the gap identified between the worker's functional abilities and work tasks and equipment.

The workplace changes included a new adjustable chair and a sit-stand workstation. The sit-stand workstation included a new keyboard tray and monitor arm mounted to her existing desk This new equipment provided sufficient adjustment so she could use her computer in both a seated and standing position. There were no changes in the ratings of the ergonomic risk factors after the workplace changes were implemented (see Table 1). However, worker pain was reduced and sustained seated positions were eliminated. Standing positions were used approximately 30% of the workday compared to 1% of the workday before the workplace changes were implemented.

Figure 1:O-ring installation before intervention.

Figure 2: O-ring installation after intervention.

Figure 3: Academic Advisor's workstation before intervention.

Figure 4: Academic Advisor's workstation after intervention.

Table 1: Upper extremity risk factor ratings before and after interventions are implemented.

| | O-Ring Installation | | Academic Advisor | |
|---|---|---|---|---|
| **Risk Factors** | **Before** | **After** | **Before** | **After** |
| Repeated and sustained exertions | 5.5 | 2.5 | 3 | 3 |
| Force | 7, 1 | 2, 0.5 | 1, 2 | 1, 2 |
| Contact Stress | | | | |
| Finger/hand | 5.5, 1.5 | 3, 1 | 1, 3 | 1, 3 |
| Wrist/palm | 5.5, 1.5 | 2, 1 | 1, 2 | 1, 2 |
| Forearm | 0, 0 | 0, 0 | 1, 3 | 1, 3 |
| Elbow | 0, 0 | 0, 0 | 1, 3 | 1, 3 |
| Posture | | | | |
| Wrist flexion/extension | 9, 3 | 5, 2 | 3, 5 | 3, 5 |
| Wrist radial/ulnar | 4.5 3 | 5, 1 | 2, 5 | 2, 5 |
| Forearm | 7.5, 0.5 | 8, 3 | 4, 7 | 4, 7 |
| Elbow | 7, 3.5 | 6, 3 | 4, 5 | 4, 5 |
| Shoulder | 8.5, 3.5 | 6, 2 | 1, 4 | 1, 4 |
| Neck | 7.5, 2.5 | 5, 2 | 1, 4 | 1, 4 |
| Back | 5.5, 1.5 | 1, 0.5 | 1, 4 | 1, 4 |

10 point rating scale (peak, average) = 1-3 Low, 4-6 Medium, 7-10 High

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# LYING DOWN ON THE JOB:
# CASE STUDIES IN WORKING WHILE RECLINED

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## ABSTRACT

There are many reasons why a person might need to work at a computer while in some degree of recline. Although a number of chairs are available that can accommodate a recumbent position, equipment for the proper placement of the monitor, keyboard, mouse, and other accessories is harder to come by and must often be custom-tailored to individual needs. Following a discussion of some of the underlying issues, various scenarios drawn from actual cases will be described which demonstrate the range of possibilities and ergonomic considerations that must be addressed while providing this type of accommodation.

## BACKGROUND

People with lower-back problems experience one or more of several classes of symptoms broadly described as sensitivity to position, weight bearing, pressure, or constrained postures (1). Symptomatic relief from the first three of these types of sensitivities--and a concurrent increase in functional capacity--can often be obtained by working in a reclined position. This position promotes the opening up of the thigh-torso angle, reduces compression loads on the intervertebral disks, and helps distribute pressure across a larger surface area of the body (2). A reclined position can also be helpful for those who require leg elevation, experience dizziness when erect, are fixed in a significant kyphotic posture, or have other specific disability-related needs.

Options for recumbent seating are increasingly numerous. BodyBilt, ObusForme, and the Aeron by Herman Miller, along with a number of other traditional office chair models, offer significant recline in their seat and back mechanisms. The BackSaver chair is perhaps the best known of several brands that offers recline approaching a fully horizontal position. Several high-tech styles such as the NetSurfer and Microsphere are coming onto the market, while the classic La-Z-Boy recliner offers a time-honored solution. Other choices for working in recline include variations on patio furniture, couches, and bed mattresses with pillows and bolsters.

There are a number of issues that have to be considered in designing a reclined work environment. Besides the psycho-social ones of user and employer acceptance, one has to address the technique and effort required for getting in and out of position; reach limitations when reclined; the positioning of computer input devices and accessories; the positioning of the monitor and hard copy; the provision of arm support while accessing the keyboard or mouse device; accommodating a need to vary the angle of recline; and the impact of the larger chair footprint on an office space.

## APPROACH

One larger woman with arthritis and pulmonary problems needed to sit up on a bed while working as a writer from her home. She had very limited space in her room so the monitor was supported on an articulating arm mounted to the wall beside her bed and was swung into place as needed. The keyboard and trackball were placed on a small table similar to those used for eating in bed that was custom-built to fit her large size and had an angle-adjustable top surface.

Another woman in a similar situation was set up to work on a large bed supported by a "Relax'n Read" backrest pillow that provided back and arm support. A wheeled cart that rolled up alongside the bed held the computer, printer, and a monitor support arm that swung out over the bed. Barbell weights mounted on the bottom shelf of the cart served as counterweights to keep the cart from tipping when the monitor was cantilevered off the edge. An AbleTable adjustable reading table placed on the bed served as a book holder. The keyboard and trackball were fixed to a lightweight board to facilitate moving these devices on and off her lap.

Many people need only a modest amount of recline and can work successfully from a standard office chair. If working in true recline, a tall back or headrest will be needed for head support. In one instance, a woman needed to change positions repeatedly, preferring to keep her chair in a rocking mode. Unfortunately this tended to keep her out of good alignment with her keyboard. A solution was achieved by mounting a keyboard support to the chair's armrests. The keyboard and a trackball were attached to the support. The support was hinged at one of the armrests so that it could be raised up like a drawbridge to enable her to get in and out of the chair.

The major challenge when working in recline is to bring the work tools to the person. The recliner chairs typically are rather large, do not swivel, and therefore can't be positioned perpendicular to a standard desk. The commercially available ErgoPod desk is designed to address this but straddles the user in the chair and tends to limit their ability to get in and out of position. The newer Netsurfer and Microsphere products offer a complete work environment with the chair and equipment supports built into one unit. On the down side, their high prices and limited options prevent them from being a general solution. The BackSaver chair is very popular for those who need to work in recline since it tilts back to a full horizontal position. One approach for a person with very good upper body strength using this chair was to place the monitor on an overbed table that he could roll into position from the side. This person worked in a mostly horizontal position so significant monitor adjustment was required to tilt the screen down towards him. This was accomplished by attaching the monitor to a hinged base, with a threaded rod connecting the two hinged surfaces providing the angle adjustment. Since his angle of recline did not vary, the means for adjusting the tilt did not need to be sophisticated. The keyboard was mounted to the table via a standard keyboard tray mechanism that was modified to provide a significantly greater amount of angle adjustment.

Most people who have chronic back problems do not have enough strength to move a table with a monitor out of the way. One option is to mount a good quality monitor arm onto an adjacent desk or table that also supports the CPU, printer, and other needed items. The monitor arm can be moved in the horizontal and vertical planes to accommodate different positions. It can be swung out of the way to allow the person to get up out of the chair. The keyboard can be placed on a pillow, beanbag lap desk, or directly on the user's lap, as desired. Accessory items such as telephones, books, or copyholders can be placed on an adjacent fixed or lightweight rolling table. It is important to note that when the monitor arm is swung out away from the table it is attached to, a bolt-on rather than clamp-on mounting system must be used, or the device will tend to work itself loose. The tables themselves sometimes need to be anchored to a wall to prevent tipping.

Frequently the user prefers to work in a range of positions from vertical to horizontal. Consequently the height and angle of the monitor screen need to be adjusted as the person moves. One limitation of even the best monitor support arms is their lack of provision for significant monitor tilt. This is understandable because most users don't require more tilt than is available within the monitor base and issues of balance and safety arise when more than a modest angle is desired. In a number of instances the support arm has been modified to add a means of changing the tilt angle with little effort--while maintaining both the impression and reality of stability and safety as the monitor is supported over the user. One newer option is the lighter-weight flat panel LCD display used in conjunction with a special mounting arm such as the ErgoTron. Mounting the support mechanism adjacent to the chair may still require creative problem solving.

Getting in and out of the recliner chair can be very difficult for some people. BackSaver offers one model with a power tilt mechanism. This feature has been added to other chairs in the field on a custom basis. Other accessories that have been used to assist people in coming up out of a recline include a rope attached to a fixed point in front of or adjacent to the user, a floor-to-ceiling pole, and a short post mounted to the front edge of the chair in line with the arm rest. One method used to help a person push back into recline was a footplate mounted to an adjacent desk.

A trackball is typically used more often than a standard mouse because arm motion is more difficult when in a reclined position. In addition, if the work surface is at an angle the mouse will keep sliding down. Many people working in recline prefer to use a split-style keyboard because their arms tend to rest further down at their sides, making it harder to bring their hands to their midline. Additional support under the elbows is required when in significant recline as the arms are working against gravity. Small pillows or foam blocks can fill this need.

## DISCUSSION

While working in recline is an important accommodation for many people, significant problem solving is often required to address all the constraints posed by physical need and space limitations. An individualized approach observing proper ergonomic principles is essential and solutions frequently incorporate a combination of off-the-shelf products and custom modifications.

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# BIO-POTENTIAL BASED ENVIRONMENTAL CONTROL SYSTEM

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## ABSTRACT

A bio-potential based Environmental Control System (ECS) has been built to assist a severely disabled person in controlling his/her immediate home environment, that is, by turning "on" or "off" home appliances. The ECS consists of a digital control box, which is activated by bioelectric potentials from controlled facial movement of the user through a transducer (electrodes) and signal processor.

## BACKGROUND

With increasing availability of home automation system, controlling ones immediate environment has been made easier through the use of x-10, a communication protocol for remote control of electrical devices. The x-10 is designed for communications between x-10 transmitter and x-10 receivers over standard household wiring. The x-10 transmitters send commands, such as, "on", "off" or "dim" to the corresponding receiver of the unit (appliance) to be controlled.

These x-10 modules have made it possible to provide an alternative control interface between the user and the appliance rather than a computer to meet the needs of a severely disabled person at a reasonable cost. An alternative control interface is a digital control box, which is activated by the bioelectric potentials.

The bioelectric potentials are ionic voltages with very low frequency and amplitude in microvolts. The ionic voltages are converted to electric voltages by the transducers (electrodes) with magnitude proportional to the bioelectric potential. These electrodes pick up potentials from all muscles within its range. This bioelectric potential is processed through the signal processor, which consists of a variable gain amplifier, which amplifies the signal, a band pass filter to filter out noise, and a DC restorer, which clamps the signal waveform to provide a good DC component.

## STATEMENT OF PROBLEM

The goal of this project is to design a digital control box with a bioelectric input for a severely disabled person who is unable to move his/her limbs or speak, but can move the facial muscles. The digital control box will allow household appliances to be turned "on" or "off"

## DESIGN

The bio-potential based environmental control system consists of three main components: the signal processor, digital control box, and the x-10 modules. The input signal to the digital control box comes from the signal processor. The digital control box acts as an interface between the user and the x-10 modules; it consists of an A/D converter, sequencing and combinational logic circuitry, and relays. The A/D converter is a zero-crossing detector that converts the analog signal from the signal processor to digital.

The logic circuitry includes timing circuits, state machine, display circuits and drivers. There are two state machines; state machine one is a counter representing the rooms, while state machine two, represents the various appliances in a particular room. These state machines sequence from one state to another at a certain clock interval. The display circuit is used to indicate the current state of the state machines. Single LEDs are arranged in matrix format, with the first row representing the various rooms in the home, while the corresponding column represent the appliance in that particular room.

A high current sinking, voltage open-collector output driver is used to drive the relays, which are high current loads. The relays act as a switch to activate the x-10 remote control. The relay is hard-wired to the x-10 remote control. The x-10 remote control sends a signal to a transmitter/receiver module, which has the appliance plugged into it.

## DISCUSSION

The bio-potential based environmental control system was designed to give a severely disabled person some degree of independence. The digital control box allows the user to control different appliances in different rooms in a home. To use the bio-potential based environmental control system; the user wears a handband with the electrodes sewn into it. The digital control box is then turned on. The first row (rooms) of LEDs start to sequence through the rooms at a certain clock interval. The user on seeing the desired room sends a signal by moving the facial muscles. This signal holds the current state of the room and the direction of the sequencing LEDs change. The corresponding column (appliances) of LEDs starts to sequence vertically. Once the appropriate LED is lit the user then send another signal, which gives the user the appropriate output depending on the previous state of the appliance.

The digital control box was designed to allow an inexpensive interface between user and the everyday household appliance.

## ACKNOWLEDGEMENT

This project was supported by the Electrical Engineering Department at the University of Massachusetts Lowell, and funded in part by the National Science Foundation. The input to the digital control box, that is, the electrodes with the signal processor was designed by Annette J. Murphy an Alumni at the University of Massachusetts. Thanks to Professor Don Clark and Mr Alan Rux of the Assistive Technology Program at the University of Massachusetts Lowell.

# ENVIRONMENT CONTROL SYSTEMS: DISCUSSION OF DESIGN CRITERIA FOR HOSPITAL BASED SYSTEMS

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## ABSTRACT

Design criteria for environmental control systems specifically intended for use in the hospital setting are discussed. Recommendations of design criteria are made for each component of the system based on the most desirable characteristics for introducing this kind of assistive technology during the acute care phase.

## BACKGROUND

Environment control systems (ECS) provide a means for individuals with disabilities to gain access to electrical devices that would be inaccessible without some kind of assistive technology. The purpose of an ECS is to increase an individual's level of independence and to maximize their functional ability. Benefits to the individual include improved self-esteem, reduced feeling of helplessness, improved quality of life, decreased need for paid attendants, and reduced demands placed on family members and caregivers.

Exposure to an ECS during a patient's acute rehabilitation stay in the hospital has been identified as a factor in a client's decision to use an ECS after discharge (1). Within the acute care environment a patient is more likely to get better initial training using an ECS since it is incorporated into the overall rehabilitation process and the patient has regular interaction with the provider. This facilitates the familiarization of the user with the system and problems can be solved faster since the provider can be easily reached. In addition, use of an ECS in the hospital also allows the professional who is recommending equipment for home use with a good means of evaluating the compatibility of the different systems with the user's needs, capabilities, and preferences.

A standard ECS is either a stand-alone or computer based system that usually allows an individual to control telephones, lights, nurse call systems, bed controls, television, and other electronic devices. This increased accessibility of electrical appliances and other devices enables individuals with disabilities to directly interact with their environment. The basic means of transmitting the control signal in existing ECS are: direct wiring, X-10 modules, ultrasound (US), infrared (IR), and radio frequency (RF).

Access methods for integrated ECS include a variety of switches (button, leaf, pneumatic, etc.), voice access, remote controls, and computer interfaces. The switches are used in conjunction with an automatic or directed scanning interface. Automatic scanning requires activation of a switch to initiate the scanning sequence, whereas for directed scanning the switch is used to scan through the menu items until the desired item is reached. Voice access requires the user to train the system in order to achieve reasonable accuracy, that the user have a consistent voice pattern, and that the environment is free of excessive amount of noise which may interfere with the recognition.

Special issues involved in hospital ECS applications include widely varying user abilities, numerous health care providers interacting with the ECS, and electrical interference considerations. These issues have a significant influence on the design of hospital based ECS.

## STATEMENT OF PROBLEM

Most ECS are designed for use at home. Only one commercial system is specifically designed for a hospital setting and just a few have the flexibility to be used within this environment. Additional problems commonly encountered with ECS in the hospital setting include insufficient training of staff and patients, interfaces that are difficult to position and/or understand, inappropriate access methods, and an entanglement of cables around the bed and floor. A study by Holmes et al. (2) found that in the majority of the hospitals, Occupational Therapists were the primary professionals responsible for evaluating and recommending ECS in their facility. Since this is only one of their many responsibilities, the design of an ECS for hospital use should not be complex and should not have many technical support requirements.

The goal of this paper is to identify important ECS design specifications for use in the hospital setting. Current systems lack the versatility to provide all the features necessary to meet the needs of a wide range of patients.

## DESIGN CRITERIA

*Stand-Alone vs. Computer Based ECS.* A stand alone ECS is recommended for use in the hospital setting because it provides greater mobility, durability, and less complexity. Most available integrated ECS are computer based. Even though computers provide greater flexibility, they add complexity to the set up and training process and they usually need very specialized technical support; therefore they are not recommended for use within the hospital setting. The ECS should be straight forward to set up, easy to operate, able to use any standard interface switch, keep the use of cables to a minimum, and permit different degrees of environmental control to meet the needs of a wide range of users.

*Control Signal Transmission.* The control signal for nurse call and television should be transmitted through the same path utilized by a regular hospital pendant when possible. While the system should employ the same access methods and provide the same control signal as home based systems, transmission methods in the hospital are limited to direct wiring and possible IR for television due to possible interference with other equipment. Direct wiring should be used for bed control and other optional appliances that the patient might request and is recommended for safety reasons, since it is the best way to isolate one room from another.

*Modularity.* Modularity allows for only the most appropriate controls to be made available to a patient to meet specific needs. Since many individuals, especially acute patients, can find new equipment confusing, the amount of control they have over their environment may need to be limited initially with the option to increase the amount of control as progress is made.

*User Interface.* The system should allow a variety of user interfaces. These should be reliable, repeatable, and be able to accommodate individuals with a variety of disabilities. Reliability of the input method is crucial, especially for nurse call. Switches should be easy to reposition to ensure that the nursing staff is able to keep the interface properly positioned without too much difficulty. Voice access is not recommended since environmental noise such as equipment alarms may interfere with recognition in a hospital setting. Furthermore, the fact that many acute patients are not be able to reproduce a consistent pattern of voice due to the use of mechanic ventilators, medications, and/or weakness may prevent the patient from receiving optimal training and using voice as a reliable input method. This lack of reliability might lead to frustration from the patient and prevent him or her of getting an early feeling of empowerment from having control over the environment.

*Display*. The items that can be controlled by the ECS should be presented in an understandable way using large labels that contain either words or symbols depending on the patient's needs and abilities. To keep the ECS as simple as possible and to make it easy to learn to use, it is recommended that the system can operate in two modes: 1) a mode in which the whole menu is always visible allowing scanning and selection from a list and 2) a mode with indirect selection through the use of menus and submenus, allowing for control over more functions. The display should incorporate clear and easily understood audio and visual feedback into the design to make it more accessible to individuals with either permanent or temporary visual or hearing impairments. This display should have the flexibility of removing unnecessary options and limiting the scanning loop only to the options that are enabled. In addition, the display should include indicators that show the current status of the system. This is especially helpful for patients who are unable to see if they have activated the nurse call.

*Mounting*. The mounting system for both the unit and the display must be as simple, secure, and durable as possible in order to reduce the number of parts and to prevent parts from becoming detached, which might become a potential danger for the patient or caregiver. The main system should be a single unit that can be set up in any flat surface or positioned behind the bed. The display should be light with a mounting mechanism that can be set up on the bed (side or back), table, wall or ceiling. It should be flexible enough to allow adjustment of the display position as well as the viewing angle. The display should have a straightforward locking mechanism to position it in the desired location, giving the flexibility to change its position when needed to allow health care providers adequate access to the patient. Satisfying these criteria should allow individuals with little or no training in the use of the ECS, as is often the case in the hospital setting, the ability to reposition the display as needed without confusion or unnecessary effort.

## DISCUSSION AND CONCLUSION

Due to the number of people interacting with a patient, interference with other hospital equipment, and the progression of a patient's abilities during their acute rehabilitation stay, an ECS for use in the hospital setting requires special design criteria. A versatile ECS that meets the criteria discussed above will provide patients with a single system that has the ability to meet their specific and changing needs throughout the duration of their stay thereby maximizing their level of independence.

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# Functional Control and Assistance
# (Topic 5)

# CLINICAL TRIALS OF BION™ INJECTABLE NEUROMUSCULAR STIMULATORS

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## ABSTRACT

Preliminary results are summarized from two ongoing clinical trials of injectable microstimulators used to provide therapeutic exercise to weak or paralyzed muscles. The first trial is aimed at reversing shoulder subluxation after stroke by stimulating deltoid and supraspinatus muscles daily for six weeks. Results of five subjects showed reductions of shoulder subluxation only for experimental subjects and muscle thickness increases in stimulated muscles. The second trial is aimed at strengthening the quadriceps muscles in patients with chronic osteoarthritis of the knee. Three subjects have been recruited. Results from the first subject indicate that stimulation increased muscle thickness and improved knee function.

## BACKGROUND

BIONs are microminiature, single channel stimulators that can be injected into muscles. They receive power and individually addressable commands from an external magnetic field. They have been shown to be safe and effective for stimulating muscles in animals(1,2) and reducing atrophy in paralyzed rat muscles(3). They offer a low-risk, reliable and cost-effective technology for delivering therapeutic electrical stimulation that can be self-administered by the patient.

Shoulder subluxation is often observed in patients who have suffered a stroke. It is often painful and can lead to the complete disuse of the affected arm(4). A few studies have shown that shoulder subluxation can be reversed over 6 weeks with daily electrical stimulation of the deltoid and supraspinatus muscles, but they have used long sessions of stimulation (4-7h/d) and less convenient technologies such as transcutaneous or percutaneous electrodes(5,6,7).

Osteoarthritis of the knee is a disease found in approximately one third of the population over 65(8). It is accompanied by pain, reduced mass and strength of thigh muscles and reduced function of the knee. Strengthening of the quadriceps muscles can reduce joint pathology(9) but many patients have difficulty achieving a sufficient intensity and/or duration of voluntary exercise.

## RESEARCH QUESTION

To determine whether electrical stimulation delivered by BIONs is safe and effective for exercising muscles, increasing their thickness and decreasing joint pathology when applied in an easily tolerated schedule of intermittent, low frequency contractions totaling ~1h/d in 2-3 sessions.

## METHOD

For the shoulder study, hemiplegic patients 3-10 weeks post stroke are randomized into a treatment group who begin regular exercise with BIONs (one implanted in middle deltoid and one in supraspinatus muscles) or a control group, who are treated conservatively. After 6 weeks, the stimulated group stops using the BIONs for 6 weeks and the control group is offered BION implants if they have become symptomatic. For the knee study, patients with chronic osteoarthritis are observed for 12 weeks to determine their baseline state. They are then implanted with BIONs near the common femoral nerve and in the vastus medialis muscle, which are used to exercise the quadriceps muscles for 12 weeks. In both studies, therapy starts 4-7 days after implantation with 2-3 stimulation sessions of 10-30 minutes each day. The intensity and duration of stimulation is gradually increased as the patient's fatigue resistance improves. Outcome measures include muscle thickness measured with ultrasound or MRI, strength and function testing, and radiographic assessment of the affected joint.

## RESULTS

All patients implanted with BIONs found the sensations associated with muscle stimulation to be agreeable and they complied enthusiastically with the prescribed treatment. There were no adverse events or complications related to the implants or the exercise treatment.

Complete results from three experimental and two control subjects in the shoulder study were available as of early December 2000. The degree of subluxation of the experimental subjects after 6 weeks of therapy was estimated by the Dv index compared with the control side, as shown in Fig. 1. Large reductions of subluxation were seen in experimental patients 1 and 2 (-87 and -111%,

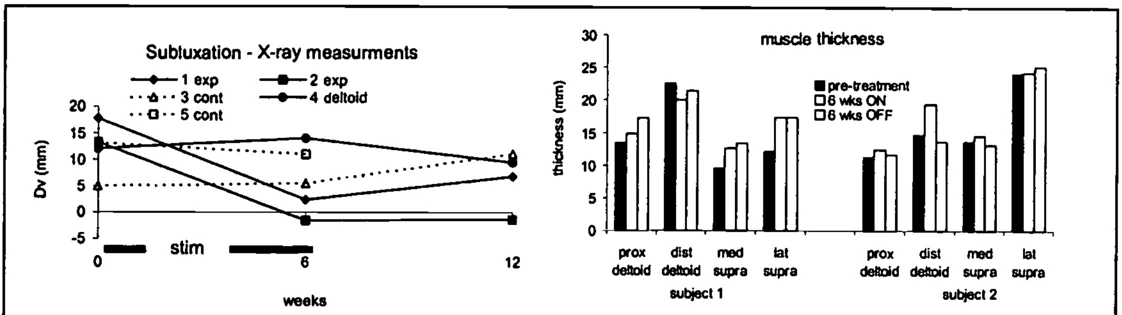


Figure 1: Shoulder-subluxation-study results. On the left, graph of the subluxation index Dv for each subject (difference between affected and non-affected shoulder). On the right, muscle thickness for experimental subjects 1 and 2.

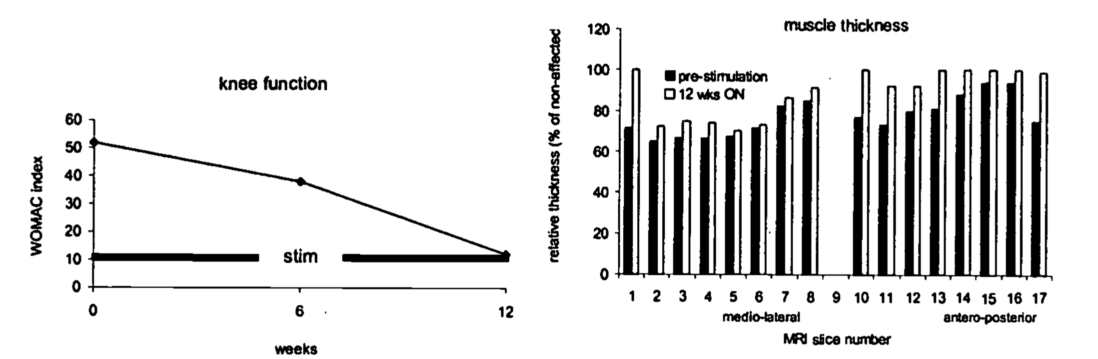


Figure 2: Osteoarthritic-knee-study results. On the left, knee function, as measured by the WOMAC index, of subject 1 over the 12 weeks of stimulation. On the right, relative muscle thickness (% of non-affected side in same subject) by MRI of rectus femoris muscle, at different locations, before and after 12 weeks of stimulation.

respectively), but not in experimental patient 4, who was stimulated only in the deltoid muscle, or in either control patient. When stimulation was discontinued (weeks 6-12), subluxation started to return in patient 1. Thickness of the stimulated muscles (measured by ultrasound) typically was maintained or increased during the stimulation period ($p<0.05$; Fig. 1), on average by 15% (range: -11 to 44%). Some of that effect carried over during the 6 weeks off therapy, possibly related to improved voluntary shoulder abduction. In control subjects, muscle thickness did not increase and often declined. In the one subject with only deltoid stimulation, deltoid thickness increased (2 to 11%, depending on location of measurement) but supraspinatus thickness did not (-5 to 0%).

In the study of osteoarthritis, three patients have been recruited; complete results from one are available. Knee function improved and pain decreased over the 12 weeks of stimulation (WOMAC index plotted in Fig. 2). Muscle thickness increased in rectus femoris in both the medio-lateral and in the antero-posterior planes by 15% on average (range 2-40%, depending on location of measurement) ($p<0.00005$).

## DISCUSSION

The results from these clinical trials are preliminary but encouraging. We estimate that 10-20 patients will be needed in each study to demonstrate effectiveness clearly. Plans are underway for additional clinical trials to address chronic shoulder subluxation and flexion contractures of the distal arm and hand in stroke patients and patellar subluxation in orthopedic patients.

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# Development and Testing of a Robotic Wheelchair System for Outdoor Navigation

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## ABSTRACT

A robotic wheelchair system must be able to navigate outdoors as well as indoors. This paper describes the outdoor navigation system for our robotic wheelchair, *Wheelesley*, which uses a vision system to avoid obstacles and to stay centered on the current path. User tests were performed on 7 able-bodied subjects using single switch scanning on an outdoor course. The outdoor navigation system reduced user effort by 74% and reduced the time needed to navigate the test course by 20%.

## BACKGROUND

The goal of this research is to provide people unable to drive a standard powered wheelchair with a mobility device that does not require the assistance of a caregiver. Robotic wheelchairs must be able to navigate in indoor and outdoor environments. A survey of powered and manual wheelchair users found that 56.6% used their wheelchair only outside, 33.3% used their wheelchair both inside and outside, and 10% used their wheelchair only inside [1]. Most prior work on robotic wheelchairs has only addressed the problem of indoor navigation.

This research project has developed a robotic wheelchair system that provides navigation assistance in indoor and outdoor environments, allowing its user to drive more easily and efficiently. Acoustic and vision based sensors are used to provide assistance. The wheelchair system is semi-autonomous, which takes advantage of the intelligence of the chair's user by allowing the user to plan the general route while taking over lower level control such as obstacle avoidance and centering on a path. The developed system has an easily customizable user interface that has been tested with eye tracking and with single switch scanning. This paper addresses the development and testing of the outdoor navigation system; for a full report on the wheelchair system, see [2].

## RESEARCH QUESTION

Can assisted navigation in an outdoor environment improve driving performance when using single switch scanning as an access method?

## METHODS

Sensors used in indoor environments, such as sonar and infrared, are not very effective in outdoor environments. Assistive navigation in an outdoor environment is accomplished using computer vision. We use a STH-V1 Stereo Head from Videre Designs mounted on the front of the wheelchair's tray to capture images of the world in front of the wheelchair. Disparities of points[1] in the image are used to compute obstacle boundaries for obstacle avoidance. The navigation system also computes the location of the edges of the current path to provide path following. Obstacle avoidance takes priority over path following. The robot will only follow the command of the path following module if there are no obstacles detected.

[1] Disparity measures the difference of the location of a point in the left and the right image of a stereo pair. Disparity is greater for closer objects and smaller for objects in the distance. You can experience this by looking ahead at a scene with some close and some far obstacles. Alternate closing your left and right eyes. Close objects will appear to move more from one image to the next than far objects do.

To detect obstacles, the disparity image is scanned horizontally and vertically, looking for changes in disparity between adjacent points that exceed a specified threshold, indicating a likely obstacle. Since disparities can not be computed for every point of the image, we consider points on either side of one or more uncomputed pixels to be adjacent. When there is a large enough change in disparity between two adjacent pixels, we mark the obstacle boundary at the location of the larger of the two disparities, which corresponds to the closer point, assuming that the closer point is the obstacle. Figure 1 shows the computation of obstacle boundaries for two scenes.

(a) (b) (c) (d) (e) (f)

Figure 1: Obstacle detection for approaching a lamppost and approaching an open stairway. (a, d): Left image of the stereo pair. (b, e): Computed disparity map. (c, f): Computed obstacle boundary points.

For obstacle avoidance, we assume that obstacles in the middle of the sidewalk are likely to be moving (e.g., people, animals, or bikes). Objects moving toward the wheelchair will move around the chair, and objects moving away from the chair will move faster than the chair is traveling. Given these assumptions, the behavior for dealing with obstacles is to slow if obstacles appear in the far center region (1.5 to 3 meters from the wheelchair) and to stop if obstacles appear in the close center region (.6 to 1.5 meters from the wheelchair).

(a) (b) (c) (d) (e) (f)

Figure 2: Path detection. (a) Left image of the stereo pair. (b) Image after median filtering. (c) Edge points found using intensity gradient. (d) Edge points remaining after filtering out points with too few neighbors. (e) Edge points minus the points in the horizon region; we are only trying to find lines for the local path. (f) Computed lines displayed on top of the points from (d).

To follow a sidewalk, we designed a local path detector. We assume that the current path (e.g., sidewalk or crosswalk) is locally straight. To find the edges of this path, the system finds the edge points in the image using the intensity gradient and filtering, then fits a line to the edge points on the left half of the image and a line to the right half of the image. Figure 2 shows a video frame and the results of each progressive processing step.

The left and right lines computed by the local path detector are used to follow sidewalks. After each frame is processed, the system computes the percentage of points that fall within 1.5 pixels of the computed line. A line with a higher percentage of points on it should be the better fit for the data, implying that the most salient edge has been found. This edge is usually the edge of the sidewalk. In addition to selecting based upon this criterion, we also require that the set of edge points contain at least 8 points. From smaller numbers, it is likely that only noise points are included in the edge set.

The system judges whether it should drive straight, left or right based upon the slope and the intercept of the selected line. Many videos of driving on sidewalks were taken to determine the normal range of slopes and intercepts for driving straight. More videos were taken with what would be considered poor driving, including going to the edges of curbs. The observed data was used to define normal ranges for the system. The current values are then passed through the function to determine whether a turn is warranted.

An experiment to test the performance of subjects under robotic assisted control and under standard manual control was undertaken to determine if robotic assistance improved driving performance using single switch scanning as an access method. The outdoor user tests followed the same protocol as indoor user tests described in [3]. There were 7 able-bodied test subjects, 3 men and 4 women, ranging in age from 24 to 31. Each subject ran the test course four times, twice under each control method. The test course was a sidewalk on MIT's main campus that includes a curve to the left and to the right. Obstacles were not placed on the sidewalk; people walking on the sidewalks were natural obstacles that the navigation system (robotic control) or subject (manual control) needed to avoid. The test course was 35 meters long.

## RESULTS AND DISCUSSION

| | Manual | | | | Robotic | | | |
|---|---|---|---|---|---|---|---|---|
| | First run | | Second Run | | First run | | Second run | |
| Number of clicks | 44.6 | (6.5) | 35.7 | (10.5) | 12.3 | (5.9) | 8.9 | (8.9) |
| Scanning time (sec) | 64.2 | (23.4) | 45.0 | (11.2) | 26.3 | (12.4) | 14.2 | (15.6) |
| Moving time (sec) | 170.2 | (14.5) | 168.1 | (19.3) | 155.1 | (13.9) | 161.7 | (16.3) |
| Total time (sec) | 234.5 | (25.5) | 213.1 | (31.9) | 181.4 | (26.6) | 175.9 | (28.4) |

Table 1: Results of the outdoor user tests. The first number is the average and the second is the standard deviation.

Results of the outdoor tests are given in Table 1. Robotic assisted control resulted in a 74% reduction in driving effort, as measured by the number of clicks required to drive the test course. Subjects use fewer clicks on the second manual run than the first manual run, as we also found with our indoor user tests. We had one subject run manually on the indoor course for 10 runs to see how much learning could reduce the number of clicks. We found that after 5 runs, the results reached a plateau that did not approach the average number of clicks required for robotic runs.

When fewer commands are issued, less time is spent scanning. This reduction is scanning time leads to a 20% reduction in time needed to traverse the test course under robotic assisted control.

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# THE HYDRATION SYSTEM

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## ABSTRACT

Individuals who do not have full use of their hands and arms need to be as active as the population at large in order to seek and maintain employment, pursue recreational activities, and achieve greater independence in daily life. The "Hydration System" is a device that seeks to extend the capabilities of current wheelchair users who are unable to easily access water during the course of a normal day at work or school. The complete system consists of a motor-driven arm, control box, and water reservoir with flexible tubing and a mouthpiece. The arm, which is fully adjustable through the use of two switches controlling left-right and up-down movement (height and distance), moves the mouthpiece to the precise location that the user desires and when not in use it can relocate behind the wheelchair. Once in position, the wheelchair occupant is able to drink fluids thus reducing dehydration and exhaustion and leading to an overall healthier body and lifestyle.

## BACKGROUND

Maintaining the correct water and nutrient balance in the human body is essential for maximizing mental and physical functioning. A commonly cited medical statement states: "chronic dehydration causes the pains and degenerative disease of the human body" [2]. A healthy diet is not just about good food choices, but also about getting the fluid needed. If people are unable to acquire adequate levels of fluids, several health concerns arise. Initial dehydration can occur in as little time as one hour, which can lead to heat cramps, heat exhaustion and eventually heat stroke. The National Research Council's fluid recommendation is nine to twelve cups of fluids per day. Most adults do not consume their recommended daily amount of water, and more than a third of the elderly population has chronic mild dehydration. This number is even greater for wheelchair bound individuals because of the difficulty in gaining access to fluids.

Acquiring fluids can be difficult in work and school settings if a person has limited upper extremity mobility. Since water fountains are not always wheelchair accessible and can be difficult to find, many wheelchair users with limited upper extremity mobility pass the day without any form of hydration. Furthermore, a simple cup and straw is not a suitable device for a person unable to move his/her upper body and head down towards the straw. These products also tend to be obtrusive and become burdensome to an individual's range of motion. The "Hydration System" is a device which aims to improve the overall health of a portion of the wheelchair population by providing them with a portable and completely adjustable fluid intake system that is always available upon demand.

## STATEMENT OF THE PROBLEM

The purpose of this project is to design a device to allow wheelchair users to have access to a water supply without having to seek the assistance of others. Products that are currently available have very limited capacities (only 32 ounces), remain on the wheelchair armrest throughout the day, and require the individual to move his or her upper body to reach the straw. Ideally, the hydration device would be simple to operate, have both left-right and up-down maneuverability, be aesthetically pleasing, and remain in an unobtrusive location until needed.

**RATIONALE**

People who have limited mobility need to be as active as the general population in order to be competitive in the professional and academic environment. Independence and self-esteem are important issues in these environments, therefore having a personal aid perform simple tasks such as providing water can be detrimental to an individual's professional and independent appearance because it distracts from the individual's capabilities (1). A system that allows such people to have complete control of their fluid intake through an easy to control switch activated arm allows them to maintain independence.

The input received from a potential user of the "Hydration System" led the project design to aim to satisfy three major requirements: 1) control the device through the use of very limited finger motion, 2) design a completely unobtrusive device that does not invade the personal space of the user and others, 3) and design a device that is small and does not attract a lot of attention. The "Hydration System" was designed primarily for the use of a college student with spinal muscular dystrophy who has little motor control of his body, but it can be used by a wide variety of other individuals as well, including the elderly population residing in nursing homes.

**DESIGN**

Water Storage Device, Delivery Tubing, and Mouthpiece

In the design of the final product, the *CamelBak "HydroBak"*™ Water Bag and accompanying semi-rigid tubing and *Bite-Valve* ™ mouthpiece were used [2]. The reservoir holds 1.5 liters of fluid and the back-pack like outer covering simply hangs behind the wheelchair (fig. 1). The tubing attaches to the reservoir and can be obtained in various lengths or cut to fit the desired length. Furthermore, a wire sleeve was used at the mouthpiece end of the tubing to ensure a proper curve and angle for the mouthpiece. The mouthpiece is a bite valve that requires minimal pressure and is a low drip device. The *CamelBak* and accompanying equipment can be purchased for approximately $40. Additionally, a water bottle and rubber tubing or a polyurethane straw can be used in place of the *CamelBak* product.

Motor Driven Arm

The metal arm is completely under the control of the user. Through the control switches, the user is able to easily direct the motor to move the arm up from its resting position behind the wheelchair to an upright Position. From here, the user can utilize the switch controls to adjust the distance and

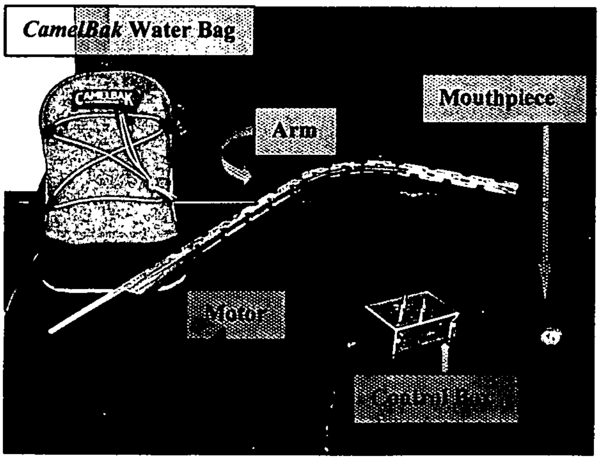


**Figure 1:** Prototype of the "Hydration System" illustrating the components of the device.

height of the mouthpiece in a left-right and up-down motion. A pulley-system directs the tubing to the right or left.

The motor runs off a separate battery powered source. This reduces the drain on a battery-powered wheelchair and also makes it usable by manual wheelchair users and bed-ridden people. Furthermore, the control box for the "Hydration System" features a low-battery warning light that alerts the user when the batteries need to be replaced. The projected cost of the complete system is $60.

Summary of Key "Hydration System" Features

- Completely portable and easy to clean
- Independent battery source does not limit use to battery-powered wheelchairs and does not drain power sources
- Only fine-motor coordination, vision, and depth perception necessary to operate the device
- User has full control of height and distance of the mouthpiece
- Arm swings away behind the wheelchair to remain unobtrusive and maintain the aesthetics of the user's personal space

## DEVELOPMENT AND EVALUATION

Several aspects of the design are still under development. A prototype device has been developed and shows promise. The ease of use and the highly adjustable nature of the system allows it to be user friendly. The "Hydration System" shows a consideration for the motor coordination and ability of the intended user and does fulfill the college student's initial design concerns. Potential users are looking forward to the development of a stronger and more versatile system.

## DISCUSSION

The functional prototype met the target design requirements. The motor driven arm is easily controlled by the two switches and the entire "Hydration System" tucks away neatly behind the wheelchair. Future work on the project includes testing the product in a more diverse environment with a focus group consisting of occupational therapists, other wheelchair users with limited upper extremity mobility, and nursing home personnel and patients who may also benefit from this device. Overall, the "Hydration System" will be cheap to the user ($60 after labor, materials, and water reservoir), and unobtrusive to their wheelchair. We expect it to be practical, and successfully employed if offered to wheelchair users.

## ACKNOWLEDGEMENTS

We would like to thank the Santa Clara University Department of Mechanical Engineering and Dr. Tim Hight, the DIET team advisor, for his support and expertise in the project.

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# ELEVATOR AID

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## ABSTRACT

Individuals with very limited upper extremity mobility can have great difficulties in reaching and pressing elevator control buttons. These issues are difficult to overcome without the direct aid of another person. A remote controlled elevator is a potential solution to this problem. While federal standards do not allow tampering with elevator equipment, the design of a small-scale working prototype of the elevator and remote control proves that it is possible. The "Elevator Aid" is a simple remote control with buttons controlling up and down elevator movements as well as door open and close buttons. The battery-powered remote control can be placed on the armrest of a standard wheelchair and is easily used by individuals with limited fine motor control. This remote can be used on any elevator that is configured appropriately with the circuitry included in the product design package. The prototype will be evaluated for effectiveness before being proposed to elevator manufacturers for incorporation into current ADA elevator designs.

## BACKGROUND

The design of elevators has improved dramatically since the Americans with Disabilities Act made building design improvements for individuals with disabilities mandatory. Most recently, emergency telephones were upgraded to a push-button type telephone that requires little strength. The hidden telephones no longer require the user to open a door and pick up the handset, but now only require the user to press a button. This development has improved access for people in wheelchairs and others with limited mobility.

However, these improvements are not always beneficial to those with the most severe disabilities. Specifically, individuals with limited upper extremity mobility encounter difficulties in reaching elevator buttons because of low muscle strength or decreased fine and gross motor coordination. A device that allows individuals with minimal motor strength to access elevators will increase independence and improve access for people with disabilities.

## STATEMENT OF THE PROBLEM

Individuals in wheelchairs with upper extremity disabilities experience problems operating elevators. The buttons are not within reach of many individuals and the inability to access these buttons causes many people with disabilities to be denied access to public buildings because of their disabilities. Many individuals have to make special arrangements in order to simply go from the first to the second floor of a building when all that is really needed is a remote for the elevator controls.

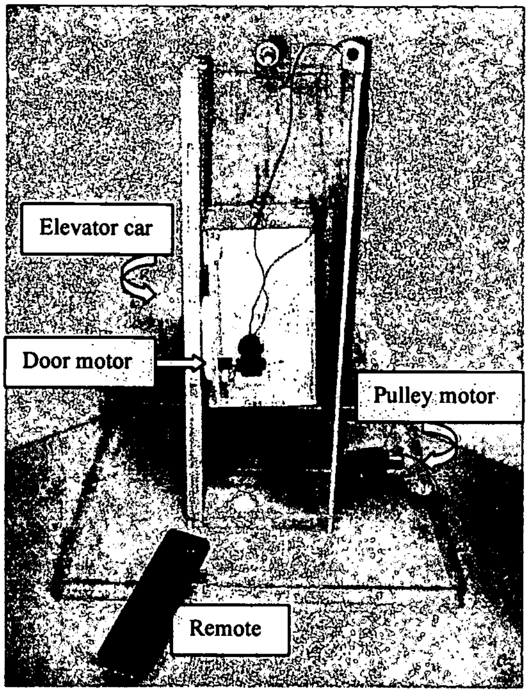
## RATIONALE

After meeting with a college student suffering from spinal muscular dystrophy, the design of the remote controlled elevator was realized and initiated because of the experiences and difficulties this student faces when visiting his professor's offices on the second floor of the building. The student would have to travel across campus to the Disabilities Resources Office in order to get assistance from personnel in going to the second floor of the fairly new building [1]. The time inefficiency and the difficulties in traveling through the building made the student very reluctant to seek help and he often chose not to discuss his questions with professors instead of seeking out the complicated string of aid he needed to utilize the elevator.

The elevator remote control was proposed and it was determined that there would be a set of guidelines in making the system effective. The system would have to be easy to operate, have buttons that were large enough to be used without error, and would have to be adaptable to other buildings with more than just three floors.

## DESIGN

The design of the "Elevator Aid" revolved around a small-scale model of an elevator. The logistics and circuitry of the mini-elevator were designed to mimic its life-size counterpart (fig. 1). Furthermore, it is intended to be generalized for use in real elevators in the future. The prototype is mainly comprised of two parts. The elevator and the remote control. The elevator moves from the ground level to second floor with the aid of a motor. The motor causes the pulley system to raise the elevator car up to the second level. Once in position, the elevator door opens by way of a small motor that moves the door using a rack and pinion system.




The remote control has four major features. The up button sends the elevator up to the second floor while the down button brings the elevator to the first floor. These function on the external motor that controls the tension in the elevator pulley system. The open and close buttons control the doors of the elevator car. Infrared signals transfer commands to the elevator control box.

The "Elevator Aid" remote control contains all the circuitry necessary to control the elevator within a small 3" x 6" x 0.5" remote which operates on AA batteries. The remote can be attached to the armrest of the wheelchair and remain unobtrusive. Once the main circuitry is installed within the elevator control box, the remote controls can be used on all elevators that have the necessary control circuitry.

**Figure 1:** The "Elevator Aid" small scale prototype functions on a pulley system controlled by infrared signals from the remote control.

## DEVELOPMENT AND EVALUATION

Several aspects of the design are promising. The initial design guidelines were met; the remote was easy to use, had buttons of adequate size, and can even become a universal system for elevator accessibility. One design issue that has been raised is the concern with emergency situations. The remote does not provide individuals utilizing it with the ability to use the elevator emergency telephones. Future designs will have to take this important concern into mind and develop an emergency call button.

The small-scale prototype can be used to propose future modifications in elevator design and accessibility to major elevator manufacturers and installers. Once the design is approved for installation in elevator control boxes, the remote controls can be manufactured and used by those needing the "Elevator Aid."

## DISCUSSION

The functional prototype met the target design requirements. The remote control is portable, simple to use, and is very small. The entire system is relatively simple and can be used in private residences as well as in public buildings. Once the device can be approved for use in a real elevator, potential users can evaluate it and contribute to future design iterations.

Overall, the "Elevator Aid" is expected to be of moderate cost to the user ($120 after labor and materials) and unobtrusive on their wheelchair. It should be practical and successful if offered to wheelchair users, corporate and federal agencies, and academic institutions in need of the product. Once the initial investment is made in installing the circuitry into the elevator control box, additional remotes can be purchased at the prices stated and can be utilized in all elevators that function on the system.

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## USING VIRTUAL REALITY TO IMPROVE WALKING IN PEOPLE WITH STROKE

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### ABSTRACT

The long term goal of this work is to construct and test a system for individuals with stroke that trains, monitors, and improves their walking characteristics including stride length, walking speed, and ability to step over objects. The proposed method is expected to be safer and physically more compact than conventional training techniques and will provide more rapid and precise feedback.

### BACKGROUND

Gait training is an essential component in enabling a person to safely function in real world environments. This is especially important for persons with gait deficits secondary to musculoskeletal (amputations, post orthopaedic surgery) and neurological (stroke, head injury, spinal cord injury, Multiple Sclerosis, peripheral neuropathy, Parkinson's disease) problems. All of these patient populations would benefit from improvements in their ability to walk. Persons with gait deficits make up the majority of the rehabilitation population and represent a substantial portion of the Veteran population.

Current gait training involves overground walking, practicing using parallel bars, and stepping over objects of different sizes and shapes that are placed on the floor. These techniques are often limited by available materials and space constraints. In addition, practicing these tasks involves a high level of risk to the patient, since failure to clear an obstacle may result in a fall.

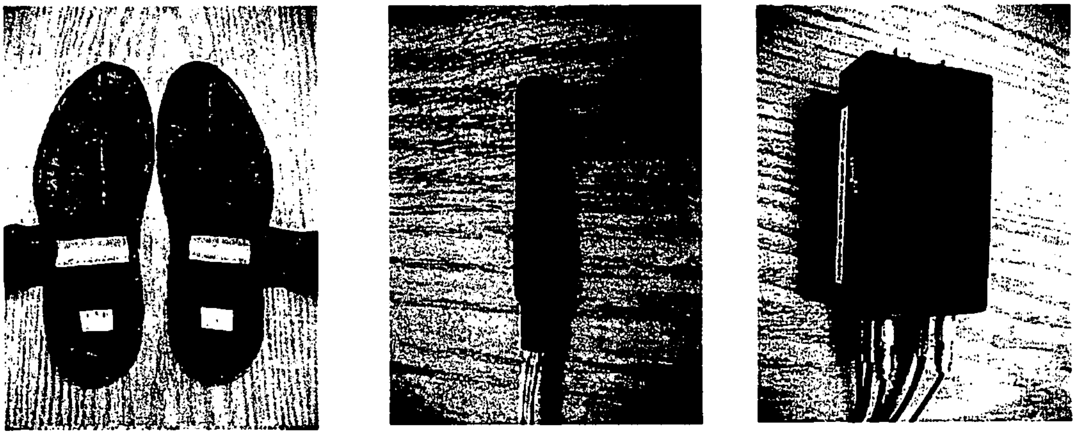
### RESEARCH QUESTION

It is expected that a virtual reality training technique will improve the ability of stroke patients to walk as indicated by measured increases in stride length, walking speed, and the ability to step over obstacles. Improved walking should also enhance their ability to negotiate steps and walk independently.

Decreasing the gait training time and preventing falls caused by inadequate obstacle avoidance can reduce health costs. Most importantly, as patients learn new movement strategies, their walking abilities will improve as will their ability to step over common obstacles encountered in the real world.

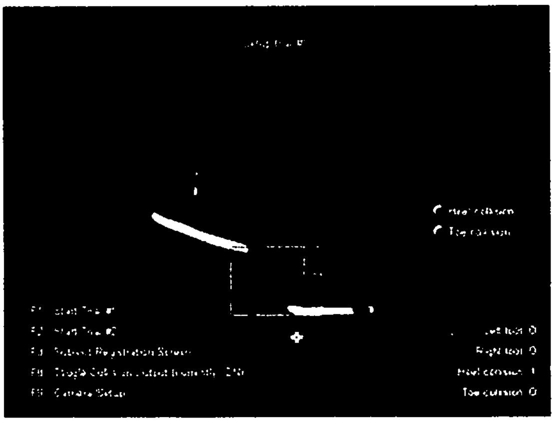
### METHODS

For the current project, we have been training subjects with stroke to walk on a treadmill while practicing stepping over computer-generated objects of different heights and lengths. A color video camera views the subjects' legs from the side. This real time image is viewed by the subject wearing a head mounted display. The computer adds virtual images of rectangular objects of varying heights and lengths at the subjects' feet. The subject is instructed to step over the obstacles on each step. The computer captures the images and detects any intersection of the user's feet with the virtual obstacles. A collision by the toe on the front edge of the object indicates that the subject has not lifted the foot high enough, while a collision with the heel on the top of the object indicates that the subject has not stepped far enough. Foot switches determine which foot is off the ground. Vibrotactile feedback is directed to the heel or toe of the foot that caused the collision. Subjects are safely held in place using an overhead harness.



Elements of the vibrotactile feedback system. Vibrators (middle photo) are placed in contact with heel and toe of each foot. The foot-switches (left photo) sense which foot is off the ground. The interface box (right photo) receives collision information from the computer system and provides a vibration cue to the heel or toe of the foot involved in a collision.

Subject wearing head-mounted display and overhead safety harness while stepping over simulated objects on a motorized treadmill.



The view through the head-mounted display shows subjects' feet in relationship with a simulated obstacle. In the photo, a collision with the heel has occurred.

## RESULTS

Preliminary results with a population of stroke subjects show improvement in walking speed, stride length, and ability to step over stationary obstacles.

## DISCUSSION

In a new study, we will extend this technique to a population of patients with progressive gait disorder. As before, simulated objects will be presented in a head-mounted or LCD display, superimposed on a real-time side view of the subject walking on an instrumented treadmill. "Collisions" between the users' feet and the computer-generated obstacles will be detected using a commercial computer imaging system with vibrotactile feedback given to the "colliding foot". The combination of visual, audio, and tactile feedback has been shown to promote more effective walking strategies with stroke patients.

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# Service Delivery & Public Policy
# (Topic 6)

## Virtual Collaboration Using Internet-Based Tools

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ABSTRACT
Virtual collaboration technologies have become less expensive and easier to use over the recent past. These technologies offer the promise of facilitating cross discipline collaboration and support in a variety of rehabilitation arenas. Video and audio conferencing gives clinicians working remotely the opportunity to consult in real-time with colleagues or experts who otherwise could not be involved. Remote control of computer technology can facilitate computer setup, troubleshooting, evaluation. Virtual coordination through web-based organization tools such as virtual calendars, online presentations and email lists is made possible through technology. This paper describes the experiences of the RERC on Communication Enhancement using these tools to facilitate communication between partner sites.

### BACKGROUND
The Rehabilitation Engineering Research Center on Communication Enhancement (AAC-RERC), based at Duke University Medical Center was established to conduct research and development to improve Augmentative and Alternative Communication (AAC) technologies. In order to appropriately respond to the diverse priorities proposed by the National Institute on Disability and Rehabilitation Research (NIDRR), a virtual research program was proposed, allowing the AAC-RERC to enlist expert researchers in the various fields called for in the NIDRR priorities. The AAC-RERC is a partnership of seven distinct locations, which makes extensive use of electronic and Internet technologies to facilitate collaboration. Five of our partner organizations are connected to the high speed, next generation Internet2.

### OBJECTIVE
Our interest in these virtual tools is based on several realities. It is important for the researchers to be able to collaborate but that it is difficult and expensive to meet regularly face to face and that this could be a model for future research in being able to get the experts in the field to collaborate without expectation of relocation. The objective of this paper is to describe the experiences of the AAC-RERC in using several virtual collaboration tools.

### APPROACH
The AAC-RERC has focused its efforts in the use of inexpensive or free virtual collaboration tools. In most cases there are commercial solutions for each of the collaboration topics we discuss below, but they often come with significant costs.

*Virtual Conferencing:* The AAC-RERC has made extensive use of audio conferencing by way of traditional telephone teleconference. Several sites have been using voice of IP (VoIP) technologies. VoIP is the use of the Internet infrastructure rather than the traditional phone company infrastructure to carry the call. We have done some video conferencing as well and plan to expand the use of video collaboration this year. The technology has improved significantly over the past few years. Recently, several sites have been investing in VoIP phones, such as the Balanced Audio Telephone (1) and in combination with the free Microsoft Netmeeting (2) program (Figure 1) or services such as Firetalk (3) and Dialpad (4), we have been conducting VoIP, point-to-point conversations with good quality. The advantage of these technologies is the cost

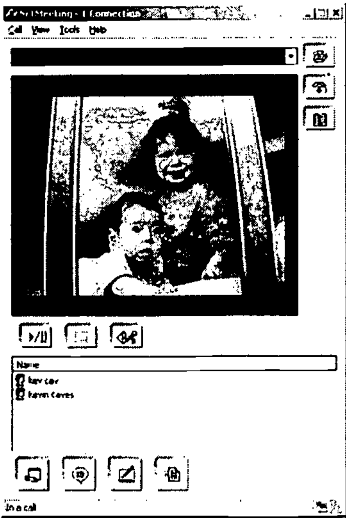

Figure 1: Screenshot of Netmeeting Video Conference

savings of the toll call. There are limitations though with these technologies including in some cases decreased audio quality, audio delay, and the limitation that the call must be placed through a computer to another computer. Many of these issues are being resolved as technology improves, for example there are now free VoIP services that let you place toll-free long distance calls from a computer to a standard phone, or directly from phone to phone. The number of participants involved in virtual conferencing influences the selection the software and technology required. NetMeeting supports video as well as audio when used with a computer camera. It supports application sharing, whiteboard, and chat. Firetalk is an audio only virtual conferencing application that allows point-to-point and limited multi-point communications.

*Remote Computer Control:* Remote computer control has been used to demonstrate software to remote sites, conduct computer training and technical support. The tool we have been working with is Virtual Network Computing (5) (VNC) from AT&T Laboratories, Cambridge, UK. VNC allows a person to give control of his computer to another person at a remote site. We have used this technology during software demonstrations and this method of demonstration has several advantages including that the demo software can reside locally on the host machine simplifying installation and support. Both parties see the same screen and the VNC software can allow the remote user to actually interact with and control the application. The host can assist the remote user if he has any difficulty by taking control of the keyboard and mouse. Finally, VNC is cross platform working across PC, Macintosh and UNIX platforms (Figure 2). We have had some problems with VNC including incompatibility with video conferencing software. Additionally there is a security concern with using this and other remote control technologies in that these technologies are designed to provide access to the local computer from the Internet.

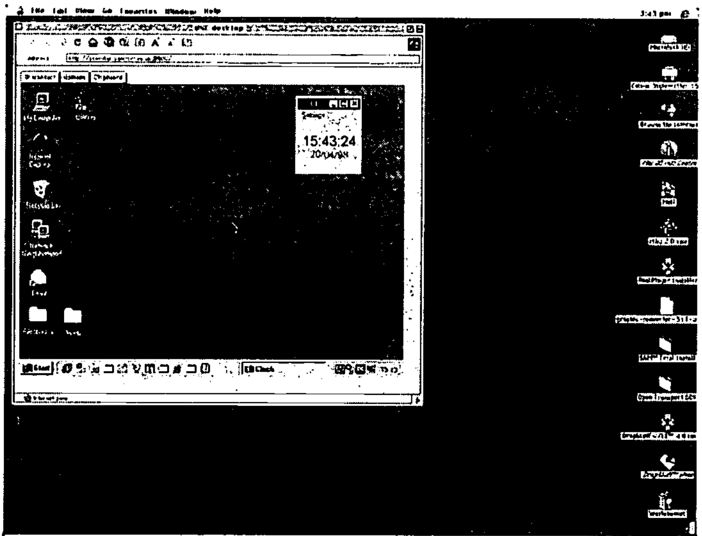


Figure 2: VNC Screenshot of MS Windows Desktop Being Accessed from a Mac OS Desktop

*Virtual Coordination:* Some of the biggest challenges of conducting a virtual research program include the coordination of the research program, project tracking, communication and team building. We have employed several simple free tools to assist with this aspect of our collaboration. We make extensive use of email and have set up a simple project directors list serve. We also use a password protected, web-based calendar that each of the project directors has access to.

The virtual calendar serves several purposes. The online calendar gives the AAC-RERC a single point of reference for meetings, deadlines, conferences, presentations, vacation schedules and the like. The calendar can accept single and repeating events and has the ability to send user specified, automatic email reminder messages. The online calendar provides an efficient way to schedule meetings, conference calls or virtual conferences. The date and time of the meeting are obvious at a glance. In addition, a dialog box can be included that provides information about the agenda, the expected participants, phone numbers, and passwords. Notification of participants can be managed through the automatic email notification. For example, the morning of a team meeting the virtual calendar is instructed to send out an e-mail announcement to each of the participants with the agenda and conference call number. The virtual calendar supports communication to all participants in the consortium. By accessing the calendar, each participant can monitor ongoing events and the activities. Finally, the virtual calendar provides a historical record of the activities of our Virtual Research Center. In this way it supports accountability for preparation of reports and documents. We have chosen the free Yahoo (6) calendar (Figure 3) for several features that have facilitated communication as well as coordination.

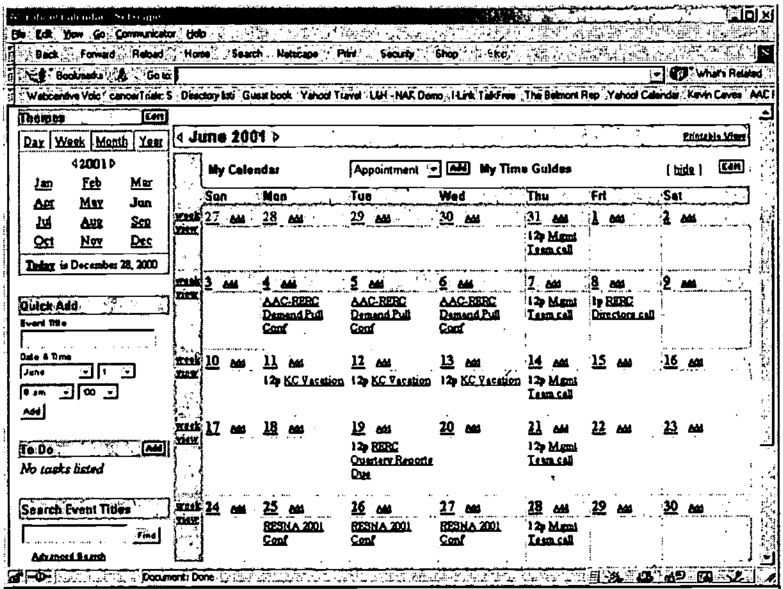


Figure 3: Screenshot of AAC-RERC Yahoo Online Calendar

*Virtual Presentations:* We have made extensive use of the Internet for project review presentations. Twice monthly, we receive a project update on a different project in the RERC. We use web-based presentations through either traditional web pages or through the creation of HTML compatible presentations using Microsoft PowerPoint. PowerPoint allows easy creation of web presentations from standard PowerPoint presentations. We have also used VNC as described above, for demonstrations of software packages during these presentations. We make use of traditional teleconference technology to carry the voice portion of the conference. These presentations have allowed for project specific discussion and dialog that would normally occur at a center based RERC.

## DISCUSSION

Virtual collaboration technologies have become less expensive and easier to use over the recent past. These technologies have facilitated collaboration and support within our RERC. Our use of web-based video and audio conferencing, remote control of computer technology, and virtual coordination tools such as virtual calendars, online presentations and email lists have made it easier for our virtual research center to operate as a center based at a single site.

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Utilizing Multiple Training Mediums to Deliver an Innovative Assistive Technology Applications Certificate Program (ATACP)

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**ABSTRACT**
Since the proliferation of the Internet and Technology, Assistive Technology Service Providers are now able to access a world of information and provide enhanced services to their consumers. Now in the fourth year of delivery, the Assistive Technology Applications Certificate Program (ATACP) is proving to be an innovative approach to acquiring 'practical' training through a program which combines on-line instruction, live training and a self directed final project. The primary focus of the presentation will center around course effectiveness with regard to specific course content areas, adult learning principles adhered to in the course, as well as outcomes obtained by course graduates.

**BACKGROUND**
The proliferation of the Internet and technology is enabling Assistive Technology Service Providers to access a world of information and provide enhanced services to their consumers. Now in the fifth year of delivery, the Assistive Technology Applications Certificate Program (ATACP) is proving to be an innovative approach to acquiring practical training through a program which combines on-line learning, live training and a self directed final project. The primary focus of the presentation will be discussion of course effectiveness, with regard to specific content areas, adult learning principles adhered to in the course, as well as outcomes obtained by course graduates. Once completed, the person obtains a certificate in Assistive Technology Applications and University validation of their skills.

**COURSE CONTENT**
In order to receive a certificate in AT applications, various strategies, materials and venues needed to be adapted and developed in order to present a well-rounded training program in all areas of Assistive Technology. The fifty-two hours of on-line instruction were developed for many reasons: 1) to increase the convenience 2) to decrease the amount of structured class time and 3) to set a level playing field for the 40-hour live training.

Specific content of the curriculum was transposed from a live training medium into an on-line learning experience through the use of various tools such as general information sharing through use of tech points and case studies, supplemental readings, web research, field trips, and on-line information sharing among fellow participants.

## ADULT LEARNING PRINCIPLES

The program is considered an in-service training for professionals active in the field. In keeping with the practical aspect of the course, emphasis is placed on active participation rather than passive learning. There are no tests in the course. Instead, participants complete "Applications Exercises" in order to apply the information presented. Participants can choose from a variety of tasks, which include answering a question regarding the information provided, completing a related field trip experience, or conducting research related to the topics presented.

## OUTCOMES

As part of the 100-hour certificate program and upon completion of both online and live instruction, participants demonstrate course competency through a required final project. Participants draw upon skills and knowledge obtained during both online and live instructional environments. Final projects specifically focus on meeting the needs of individuals with disabilities and/or an organization that serves them.

Some of the specific skills and knowledge participants draw upon include the ability to:

- Identify a wide range of applications for Assistive Technology in the home, school, work place and community environments
- Address the needs of person with disabilities through a collaborative team approach
- Acquire resources available to support Assistive Technology devices and services

The training has expanded the population of professionals who are becoming consumers of AT information. This delivery format is increasing the diversity of professions in acquiring information regarding disability and technology.

## CONCLUSION

With the field of Assistive Technology growing larger each day, there is a need for a comprehensive training program that will enable professionals to provide better services to their consumers. Through the on-line, live and project delivery of the ATACP, this training is highly compatible with the needs of today's technology utilizing professionals. By the end of the year 2001, over 1400 Assistive Technology Service Providers will have participated in the training program.

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# EVALUATION OF TECHNOLOGIES FOR DISTANCE DELIVERY OF CONTINUING EDUCATION TO REHABILITATION PROFESSIONALS

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## ABSTRACT

This paper examines the use of technologies to enhance continuing education for rehabilitation practitioners at a distance. Three types of technologies are compared: satellite broadcast or videotapes of these broadcasts, videoconferencing, and web-based technology. Various characteristics of these technologies are examined and compared in order to guide the effective use of the different instructional methods.

## BACKGROUND

The Alberta Rehabilitation Continuous Learning Network (ARCLN) was established to coordinate continuing professional development (CPD) delivered to rehabilitation professionals across the province. The network currently consists of nine sites across Alberta, and one site in Iqaluit, Nanuvit Territory. ARCLN was established based on a continuing education survey in 1998 (1). A random telephone survey sampled 203 respondents from three professions (OT, PT, SLP). Over 95% of the respondents rated CPD as somewhat or very important to personal development, current jobs and careers. Over 90% of the respondents stated they currently used personal time to review periodicals or newsletters for CPD. Over 70% of the respondents also attended an average of two presentations a year. Close to 60% of attendance at presentations required travel. The following were identified as barriers to CPD: travel (65%), cost (75%), time constraints (70%) and course content (60%). The need for a coordinating body to offer CPD (85%) was also identified. Qualitative interviews were conducted with individuals representing other stakeholders (n = 27), i.e. professional associations, Regional Health Authorities, employers, and post-secondary institutions. These stakeholders believed that they had a role in CPD, and that it was helpful in recruitment and retention.

These findings are consistent with the literature which shows that CPD is important for maintaining clinical competency (2), and for recruitment and retention (3). Distance, travel, time constraints and cost have been cited as challenges faced when accessing CPD(4). The emergence of technology-enhanced distance learning offers an important solution to timely and cost-effective CPD. Yet, these options must be introduced carefully. Many health practitioners are skeptical of distance learning. These professionals are oriented to personal contact with patients and their professional interventions often require physical contact with their patients. To be accepted among health practitioners, learning systems must be developed that are multi-faceted, focused on specific learning needs, appropriate in content and delivered using the most appropriate technology. Learning styles, economic and geographic realities and specific content must also be considered.

## RESEARCH QUESTION

Our objective is to compare four types of distance-delivered CPD using three types of technologies.

## METHODS

The four types of CPD are: (1) Live satellite broadcast with learner interaction via a toll-free number, and/or rebroadcast or videotape presentation. (2) Interactive interdisciplinary case presentations from one clinical site to the ARCLN sites via videoconference. (3) Interactive research seminars using videoconferencing to deliver from the University to ARCLN sites. (4) Web-based courses.

Data were collected using on-site satisfaction surveys, mailed surveys, focus group sessions and interviews with learners and other stakeholders.

## RESULTS

A comparison of the characteristics of the different delivery methods are presented in the Table.

| Characteristic | Satellite | | Grand Rounds/ Research Seminars | Web-based Course |
|---|---|---|---|---|
| | Live Broadcasts | Videotapes | | |
| Provider | External to ARCLN | External to ARCLN | Community/ University | University |
| Delivery Method | Satellite | Videotape | Videoconference | Personal Computer |
| Timing | Synchronous (Real time) | Asynchronous (Any time) | Primarily Synchronous | Primarily Asynchronous |
| Course Material Preparation | Limited | Limited | Limited | Extensive |
| Location | Fixed | Flexible | Fixed | Flexible |
| Dedicated Equipment | Yes (Satellite Dish) | No | Yes (Videoconferencing Equipment) | No |
| Travel Required | To equipment sites | No | To equipment sites | Not required |
| Practically serve large areas | No | Yes | Requires appropriate videoconference facilities | Yes |
| Scheduling conflicts | Possible room use conflict | No | Possible, room use conflict | No |
| Orientation required for participant | Minor (for submitting questions) | No | Minor (for submitting questions) | Yes (if not familiar with method) |
| Interaction with Instructor | Limited | More limited | Extensive | Extensive |
| Method of Interaction | 1-800 number or email | Email | Videoconference | Computer conference email/ phone |
| Practical Length | 1 to 4 hours | 1 to 2 hours | 60 to 90 minutes | 5 hours/week for multiple weeks |
| Replacement Workers | Usually | Not normally | Usually | No |
| When taken | Work | Off-work or work | Work | Off-work |

Technologies for Continuing Education

| Characteristic | Satellite | | Grand Rounds/ Research Seminars | Web-based Course |
|---|---|---|---|---|
| | Live Broadcasts | Videotapes | | |
| Local content | Rare | Rare | Yes | Yes |
| University credit possible | No | No | No | Yes |
| Instructional methods | Primarily didactic | Primarily didactic | Didactic and Learner-centered | Learner-centered |
| Size restrictions | Size of room at site | Unrestricted | Size of room at site | Limited by facilitator learner ratio |
| Audience | Group | Individual/ Group | Group | Individual |
| Payments | Annual subscription | Annual subscription | Phone line/per site/per use | Per course |


## SUMMARY

This study compares different distance delivery methods. The research data indicates strengths and weaknesses of these different distance methods. For most effective delivery these characteristics need to be understood.


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# USING TELE-REHABILITATION TO INCREASE ACCESS TO CONTINUING PROFESSIONAL DEVELOPMENT

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## ABSTRACT

This paper presents preliminary results of a study that examines learner satisfaction with the use of videoconferencing/telerehabilitation technologies to enhance continuing education delivered to rehabilitation practitioners at a distance. A total of five interdisciplinary case presentations were presented over a four-month period across a maximum of 10 sites, some rural and some urban. A satisfaction questionnaire was completed by 141 participants and provided data on participants' satisfaction with the presenter, administration of the seminar, facility, technology and application of the knowledge gained. Overall, the participants were satisfied. Many of their recommendations for improving the use of these technologies are being implemented immediately.

## BACKGROUND

Telerehabilitation refers to "The remote delivery of rehabilitative services such as monitoring, training, and long-term care of persons with disabilities, using telecommunications technology" (1). Technologies at each site vary depending on the hardware, software and method of transmitting the audio, visual and biomedical data. In addition to the initial investment in infrastructure and human resources, successful telerehabilitation implementation requires long-term planning to keep up with the rapid advances in technology. Using the technology for multiple applications helps ensure that the investment is cost-beneficial. We have used telerehabilitation for distance clinical supervision of students, consultation to clinicians, bringing case studies to the classroom, providing access to specialized rehabilitation services such as seating assessments and assistive technology, facilitating interdisciplinary rounds and increasing access to continuing education (2, 3). These benefits have also facilitated the recruitment and retention of rehabilitation professionals in some rural areas.

## RESEARCH QUESTION

The objective of this project is to examine learner satisfaction with the application of telerehabilitation technology for continuing education sessions delivered in the format of interdisciplinary clinical case presentations (grand rounds).

## METHOD

A total of 10 partner sites participated in this project, although not every site participated in each case presentation. Nine sites were in rural or urban Alberta and one site was in Iqaluit, Nunavut. The University served as the coordinating site, but the moderator of a session was located at the site of the presenter or clinical expert. The equipment that all sites used were videoconferencing or telehealth equipment with the exception of one site which used a videophone and displayed the image onto a large screen in an auditorium. For transmitting live two-way videoconferencing, we utilized 3 BRI (6 ISDN) connection at 384 kbits/s for 8 sites, Ku-Band satellite at 384 kbits/s for one site, and 1BRI (2 ISDN) connection at 128 kbits/s for the site that used a videophone. A structured protocol was developed by the coordinating site to ensure that there was consistency in how each host site would moderate the sessions. All sessions were one hour in duration and were promoted through the coordinating site (ARCLN) and the host sites.

Learner satisfaction was evaluated using a 17-item questionnaire that participants completed on site after each case presentation seminar. Fourteen of the items evaluated the presenter, administration of the seminar, facility, technology and application of knowledge. Participants rated these items on a Likert scale of 1 to 5, 1 indicating strongly disagree, 2 disagree, 3 neutral, 4 agree and 5 indicating strongly agree. The last three items were open-ended questions that asked the participants how they would apply the knowledge gained to their practice, suggestions for future topics or speakers, and how they found out about the seminar.

## RESULTS

A total of five interdisciplinary clinical presentations have been delivered from September to December 2000. The topics covered Assistive Technology, Osteoporosis, the ICIDH-2, Multiple Sclerosis and Chronic Pain Management. A total of 141 surveys have been completed. The results are presented in the Table. Overall, the participants agree or strongly agree with the items on the satisfaction questionnaire.

| Item (n) | Mean | SD |
|---|---|---|
| The presenter(s) demonstrated thorough knowledge of the content area (141) | 4.56 | .51 |
| The teaching methods used were effective (139) | 4.14 | .64 |
| The presenter appeared comfortable with videoconferencing/telehealth (140) | 4.21 | .64 |
| There were adequate opportunities for questions and discussions (127) | 4.19 | .82 |
| The seminar was well organized (137) | 4.15 | .74 |
| I learned about this seminar in acceptable amount of time to plan my (139) | 4.36 | .75 |
| The travel time to get to the facility was acceptable (132) | 4.42 | .76 |
| The facility's environment was free of distractions (135) | 4.26 | .94 |
| The sound quality was acceptable (140) | 3.97 | .89 |
| The image quality was acceptable (138) | 3.93 | .84 |
| Videoconferencing technology was appropriate for the content material (140) | 4.19 | .75 |
| Information will help enhance my practice and improve my skills (137) | 3.99 | .68 |
| I would be willing to participate in future tele-learning sessions (140) | 4.35 | .60 |
| I would recommend this type of session to my colleagues (105) | 4.27 | .62 |

The qualitative data collected using this questionnaire provided useful suggestions for improving the delivery of continuing education using this method and how to better use the technology. Some of the suggestions related to scheduling (e.g., Starting and finishing on time) which is less flexible when technologies are being used compared to traditional face-to-face presentations. More time is needed at the beginning to ensure that all of the sites are "online" and that the technology is functioning at each site. These suggestions were used to enhance the protocol. For example, speakers were asked to repeat questions from the audience in order to address audience microphone problems that may exist at certain sites.

A total of 88 questionnaires contained comments on how the participants would apply the knowledge learned from the seminar to their practice. All of these were positive comments. Most comments were specific and related to patient intervention, patient education, program development, improving one's teaching. For example, one respondent who attended the session on Assistive Technology commented, "It will bring a level of knowledge that can be used with my senior clients as their mobility is reduced and their ability to interact with the physical world may also be reduced". Another participant who attended the session on multiple sclerosis stated that he/she has "... Become more aware of chronic illness approach that is being used with MS and how similar approaches for other chronic illnesses are useful". Some participants commented that a session provided general background information or increased the person's awareness of interventions. For example, one person who attended the session on MS said it was ... "Good overview and resource for further learning". Another person who attended the session on Chronic Pain stated, "I have studied quite a lot of the material covered over the years on my own or during different therapies. This reinforced what I've already learned."

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# DETERMINING THE EFFICACY OF POTS BASED TELEREHABILITATION FOR WHEELCHAIR PRESCRIPTION

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## ABSTRACT
This study aims to establish a scientific basis for the reliable use and limits of video conferencing for remote prescription of Assistive Technology (AT) using "Plain Old Telephone System" (POTS) lines to transmit and receive the audio and video signals. The study will determine the potential of increasing the availability of AT prescription services to communities underserved due to geographical and/or transportation barriers. Video conferencing systems are used to evaluate individuals for their wheelchair needs and are compared to the findings of "In Person" evaluations to determine if appropriate standards of care can be maintained. Preliminary results are discussed.

## BACKGROUND
New telecommunication technologies with improved video conferencing capabilities, are being developed in response to a huge and lucrative potential market. These technologies include cable modems, high-speed digital phone lines (ADSL) and wireless systems (1). However because of low population density, rural areas are likely to benefit last from these developments. People in these areas also have lower access to quality health care services (2). In his 1996 work, Jones provides information on current use of assistive devices for mobility in the US (3). Their work shows that in the US, a total of about 6.4 million individuals use canes, walkers, scooters or wheelchairs. As the year 2020 approaches he predicts an increasing population with impaired mobility that will create a challenge that is not being met today because of a shortage of qualified professionals. One way in which the growing need for services may be met is by increasing the reach of existing rehabilitation centers and skilled professionals by the use of communication technologies. Since regular phone connections are ubiquitous within the US our project utilizes video conferencing over POTS lines, termed TeleRehab (TR) (4). TeleRehab has been demonstrated in different settings including follow-up in traumatic brain injury and SCI (5), wheelchair prescription in a qualitative small scale pilot study (6), pressure mapping (7), and site evaluations (8).

## RESEARCH QUESTIONS
With defined operational protocols, can experienced clinicians using TR technologies:

1. Reliably determine if the TR process is appropriate and safe for a specific individual?
2. Reliably provide accurate decisions regarding the need for a wheelchair, at a detailed level?
3. Reliably obtain accurate assessments of medical history and physical examination?

## METHOD
Clinicians: Four licensed clinicians: two occupational therapists (OT's) and 2 physical therapists (PT's) with experience in seating and mobility evaluations conduct the mobility assessments.
Model Patients: "Model Patients" will be recruited who are over 18 years of age, less than 250 pounds weight and wheelchair users with no active pressure ulcers. Their diagnoses will include

Spinal Cord Injury, Multiple Sclerosis and Cerebral Palsy. "Model Patients" will receive training in how to act as "Standardized Patients" and in how to be consistent in the portrayal of their role (9).
Assistants: The "Assistants" will carry out the mat evaluation component of the TR assessment under the guidance of one of the clinicians from the remote location. Assistants will be provided consistent training in transfers and range of motion (ROM) techniques.
Experimental Design: An experimental crossover study design has been developed. The clinicians will conduct "In Person" (IP) and "TeleRehab" (TR) mobility assessments, on 20 "Model Patients". This will take place in two different locations: at the VA Human Engineering Research Labs (HERL) and at the University of Pittsburgh Center for Assistive Technology (CAT). None of the four clinicians will have prior knowledge of the subjects. Model Patients physically located at the HERL will receive a TR assessment, via the CAT. On the same day, the Model Patient will crossover to receive an IP assessment at HERL with an on-site clinician. Neither clinician will be in contact with the other or will have seen the results of the previous evaluation. The same Model Patient will go to CAT 3-7 days later to receive an IP assessment and crossover TR assessment via HERL. The order of evaluations will be alternated in order to reduce bias due to carryover effect.

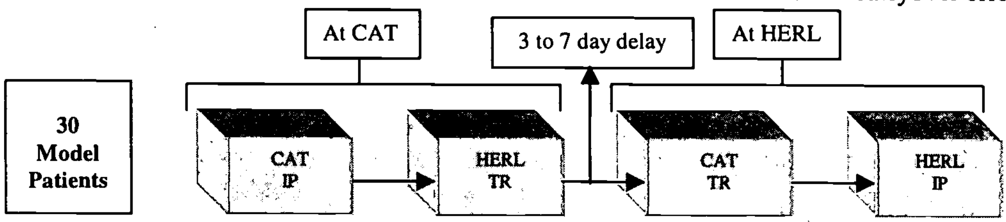


Figure 1 Graphic of experimental design

Assessment/Evaluation: The assessment will consist of an interview; a mat evaluation; data collection of range of motion and dimensions; and prescription recording. The interview with the "Model Patient" consists of access to information from a standard information sheet; and an interactive session determining mobility goals, appropriateness of these goals, diagnosis, any changes in condition. The mat evaluation is a physical motor and measurement evaluation either carried out by the clinician in the face-to-face situation or under the guidance of the clinician by the assistant via TR. The purpose of the mat evaluation is to establish passive and active ROM of the upper and lower extremities, any pathological movement patterns, sitting and transfer skills, spinal orientation, and functional abilities related to mobility. The clinician or assistant will record linear and angular measurements as required by the data collection form and setting.

## RESULTS/WORK TO DATE

Study Aims: The study has three main aims: a) to develop a data collection instrument to allow scientific comparisons; b) to determine if reliable decisions can be made using TeleRehab technology; and c) to develop a qualitative understanding of equipment requirements.
Data Collection: A team consisting of a Physiatrist; Statistician, 2 OTs; 2 PTs and a Rehabilitation Engineer have developed comprehensive data collection forms to record information on the characteristics of the Model Patients, their environments; and the details of the prescriptions. The forms were derived over a series of iterations and reviews from a collection of existing in-house forms and the work of the Assistive Technology Program in Tucson (10).
Technology: This portion of the work involves experimentation with portable telephones, wireless microphones and video links and conference style speakerphones. A reliable and understandable audio link is a fundamental component of video conferencing, which was readily achieved using a conference type speakerphone.

## EFFICACY OF POTS BASED TELEREHAB

Pilot Study: 4 pilot TeleRehab evaluations with staff and students simulating model patients and assistants have been completed. These pilot tests have enabled decisions to be made regarding equipment type and configuration to optimize performance of the TeleRehab experience. Connection rates of 26.4k provided adequate video and audio. Connection times varied between approximately 45-75 minutes.

## DISCUSSION

Critical to the perceived effectiveness of the video conferencing session is the reliability and quality of the audio link as compromises in quality of the audio were observed to cause the clinician to be distracted from the evaluation. To help with communication and explanations a total view of the clinician allows "body language" to be observed by the assistant. In addition, set up and usage of the TR equipment should be as simple as possible at both sites to enable the evaluation to take precedence. Potential experimental shortcomings include: small sample size; lack of consistency of needs presented by Model Patients over the 4 evaluations (training and review of video recordings will reduce this effect); lack of congruence between clinicians (a carefully structured data collection system ensures that there is a common data set from which prescription decisions can be made).

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# THE DEVELOPMENT OF A REGIONAL ASSISTIVE TECHNOLOGY RESOURCE CENTER

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## ABSTRACT

In many regions, services involving assistive technology are provided by a large dispersed group of organizations, rather than consolidated in a single rehabilitation center. This structure inhibits the formation of interdisciplinary teams, and generally precludes an engineering presence in decisions regarding the use of assistive technology. This paper describes the development and operation of a small, university-based center that serves as a technical resource to regional service providers. The center provides information concerning the availability and use of assistive devices, engineering design services and networking opportunities for local service providers, therapists and educators.

## BACKGROUND

The interdisciplinary team approach is a proven service delivery model in the field of rehabilitation. Traditionally the team has included some or all of the following disciplines: physician, nurse, social worker, physical therapist, occupational therapist, speech and language pathologist and school or vocational counselor. In recent years, a rehabilitation engineer may also be part of the team. Newer views of the interdisciplinary team would define its members in the broader categories of researchers, clinicians, funders and consumers (1). Large rehabilitation centers are structured to have the capability to assemble an appropriate interdisciplinary team for each individual with a disability.

Many regions lack a large rehabilitation center and are served instead by a diverse array of smaller service providers including state and local governmental agencies, social service nonprofit agencies, volunteer agencies and school systems. In these regions, it is unlikely that any single agency has the internal diversity of skills to fully implement an interdisciplinary team approach. In these situations, it is very unlikely that any of the agencies has a rehabilitation engineer on staff. The central Massachusetts region fits this description. The region is comprised of 60 cities and towns with a population of 732,000. The major city, Worcester, has a population of 167,000. Within this region, a large number of organizations provide services to persons with disabilities. There is a lack of infrastructure coordinating the delivery of these services. There is also little engineering presence in the decisions regarding the use of assistive technology (AT).

## OBJECTIVES

The university-based Assistive Technology Resource Center (ATRC) was established to achieve two objectives related to the use of assistive technology.

1. To provide a centralized information resource for rehabilitation professionals within the region.
2. To provide a technically based resource for either the modification, or the design and development of customized assistive devices.

## METHODS

Since the purpose of the ATRC was to address a local/regional need, startup funding was requested and obtained from a local charitable foundation that focused on health care. Two engineering faculty members acting as co-directors and a graduate student center manager are the key personnel. Preliminary meetings were held with some provider agencies to establish initial contacts and gain a better understanding of their needs. We then convened a focus group comprised of members from service provider agencies. This focus group identified 5 needs and opportunities that could be addressed by the ATRC, including education about AT devices, development of a central information resource, provision of design expertise, offering fabrication and repair services and provision of networking opportunities among rehabilitation professionals. The needs and opportunities identified by the focus group governed the development of the ATRC.

The ATRC holds quarterly meetings for area rehabilitation professionals. Approximately 40 individuals representing 24 agencies are on the Center's mailing list and have attended one or more meetings. These meetings serve as a forum for reporting on past ATRC activities and soliciting ideas for new activities. The meetings also focus on networking and exchanging information on assistive technology.

A web page was developed to serve as an information resource about AT. The Bobby-approved site contains information about the Center and links to other area service providers. The web page can be used as an entry point to additional information resources thru links to manufacturers, distributors and organizations that specialize in AT and disability issues.

The ATRC has used two modes of operation to provide technical assistance to cooperating organizations. First, we have provided direct onsite services with these organizations. In this mode, personnel from the ATRC jointly participate with other rehabilitation professionals in a team approach directed toward meeting the needs of a specific individual. In the second mode, cooperating agencies have sponsored class projects in design and rehabilitation engineering courses as well as sponsoring more extensive student projects. Here, members of these agencies and the Center directors facilitate the interaction between university students and persons with disabilities, usually in a classroom setting. At least one meeting is held to define the problem. Student teams develop designs and generate reports for each project. The person with the disability, caregivers and agency staff are invited to attend the oral presentation of the project results.

## RESULTS

Three types of assistance have evolved which can be broadly categorized as: technical advice, development of design specifications and development/modification of customized hardware. Assistance characterized as technical advice usually involves reviewing existing product literature and writing a report, which outlines several alternative solutions based upon existing products, their costs and their respective advantages and disadvantages. One example of technical advice assistance involved an individual who needed a mounting system for his communication device. A list of manufacturers of devices that could address all the client's needs was compiled. The ATRC also made recommendations as to which device seemed the most appropriate.

Projects that develop design specifications tackle problems that require a design and analysis phase before any recommendations can be made. These problems have unique features that cannot be directly met by simply purchasing existing products although some commercial products may be incorporated into the final design. The report issued by the ATRC includes detailed design specifications so that others can fabricate the device. One recent project involved designing a lift, ramp and dock system to allow a C5/6 SCI wheelchair user access to the lake from the deck of his waterfront home. He was also provided with a number of adaptations to enable him to fish.

Several projects have involved the design and fabrication/modification of customized hardware. In these situations, a review of the product literature indicates that no satisfactory commercial device exists. The ATRC then either modifies an existing device or designs and fabricates a custom device. Costs are usually borne by the sponsoring agency. This type of assistance has generally involved low technology AT devices. For example, a keyguard for a Brailler (Figure 1) was designed for a blind boy with poor motor coordination.

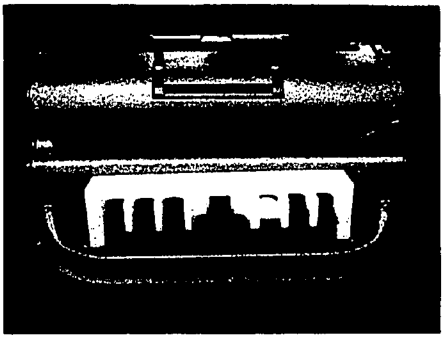

**Figure 1. Keyguard for a Brailler.**

## DISCUSSION

The development of the ATRC was strongly guided by issues identified by the initial focus group. As a university-based center, the only need and opportunity that could not be acted on was that of providing repair services. The ATRC has established long term working relationships with a number of area rehabilitation professionals. Our collaborators have noted that the ATRC brings a different and welcomed perspective to the client evaluation and into decisions regarding the use of assistive technology. The final decision to utilize any of our devices or recommendations rests with the service provider.

There were some initial barriers to the development of the ATRC. The dispersed nature of organizations that provide services to persons with disabilities made it difficult to establish initial contacts. The ATRC engaged in several outreach activities including participating in a number of service provider fairs and speaking at seminars organized by provider organizations. We used these opportunities to make additional contacts with rehabilitation professionals. Several of the participants in the Center's initial meetings became strong advocates within their regional agencies.

The professional participants came from different backgrounds. It took time to evolve a common understanding of the types and limits of the assistance that the ATRC could offer. Initially there were few requests for assistance. After completing several projects and reporting on them at the quarterly meetings, a steady stream of requests began to flow into the ATRC.

A number of ATRC projects were directly incorporated into engineering courses. Problems that develop design specifications are particularly well suited for class projects. Using AT related problems in a course setting not only increase the number of projects that can be addressed by the ATRC but also provide the students with real life problem solving experience.

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REPORT ON A STATEWIDE AT SERVICE DELIVERY PROGRAM IN A VR SETTING.

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ABSTRACT
The Georgia Vocational Rehabilitation (VR) Program has hired 25 rehabilitation professionals to provide assistive technology (AT) service delivery statewide. The multi-disciplinary teams, consisting of an OT, Engineer, Technologist and Technician, support VR Counselors in assisting VR clients to go to work. The Assistive Work Technology staff will serve over 1,500 VR clients in FY 01. In addition, the Georgia Tech Act program, Tools for Life, is unified under the same management to serve all Georgians with disabilities. Data describing service delivery categories and methods will be discussed.

BACKGROUND
As part of a major reorganization in 1997, the Georgia Division of Rehabilitation Services (DRS) made AT one of its five core service areas. DRS named the program Assistive Work Technology Services (AWTS) to emphasize its vocational nature. DRS committed 29 FTE to this new service and began recruitment in 1999, with 25 positions filled to date; recruitment continues. Tools for Life (TFL), the Georgia Assistive Technology Act Project, began in 1993. TFL supports four Assistive Technology Resource Centers across the state, a computer recycling program called REBOOT, technology-related training and technical assistance systems, peer advocacy, assistive technology legal assistance and technology lending services.

Prior to 1999, DRS contracted for AT services on an as needed basis. As the contractors were phased out, they prepared assessment guides to help train the new internal staff. The Center for Rehabilitation Technology at Georgia Tech prepared a Cognitive Impairment Assessment Guide and Mercer Univ. prepared Assessment Guides for residence and vehicle modifications. The purpose of the assessment guides is to provide a consistent level of service delivery statewide. Other guides and assessment tools are being evaluated. In addition to the assessment guides for the AWTS staff, DRS contracted for AT training for VR Counselors utilizing Tech-Points developed by The Langton Group. The AT training is to assure VR Counselors understand how to utilize fully the AT services available to them. In addition to its Continuous Quality Improvement program, a new initiative has begun to use outcome measures to determine the impact and effectiveness of the AWTS support of VR programs.

OBJECTIVE
DRS is committed to finding substantial gainful employment for people with disabilities and recognizes that AT is a critical component in achieving this goal. One criteria of Federal funding limits AWTS support to VR clients referred by VR Counselors, while the Tech Act allows for technology assistance to any person with a disability. The unified management of AWTS and TFL assures that people eligible for the VR program will receive assistance from AWTS and those not otherwise eligible will receive some type though not necessarily equivalent assistance from TFL. In FY 01, the AWTS program will serve over 1.500 VR clients, which is about 20% of the VR clients for whom work plans are prepared. The services are subdivided by funding categories collected from the existing database. These categories are listed in order of amount of funds expended:

vehicle modifications, residence modifications, computers, AT for VI, mobility and misc. The AT assessment and recommendation for an AT intervention are included in AWTS Team Report.

APPROACH

The AWTS program has assigned a Technologist to each of the 12 VR regions across the state, with an additional one in the Atlanta area due to its larger population (13 FTE). An AWTS Team is assigned to a geographic tri-region, again with an additional Team in the Atlanta area. Each of the five Teams (15 FTE) consists of an OT, Engineer and Technician. The two Teams and Technologists in the Atlanta have a Supervisor to guide and assist the administrative operations.

The Technologist serves as the regional facilitator and conducts the preliminary assessment. If the Technologist determines the client needs a more in-depth assessment or has special needs, the client is referred to the Team or members of the Team for services. In general, the OT has the most clinical experience and is referred clients who may need additional medical services; the OT advises the Counselor as to contracted medical services, such as PT or direct physician care. The OTs also may conduct an ergonomic assessment or seating and positioning assessment. Most often, the OT recommends outpatient services from local rehabilitation facilities. While ideally, the entire Team would visit each client, in practice, the Team separates in order to visit more clients based on preliminary assessment by the Technologist. The Engineer and OT usually team staff a vehicle or residence modification, with the Engineer conducting the safety and quality review. Georgia requires vehicle modifications be conducted by NMEDA certified dealers. Most residence modifications are contracted to local sources, with the contractor's progress monitored by the Engineer and Technician. Occasionally, two Technicians from adjoining tri-regions will cooperate to perform a simple residence modification where no electrical or plumbing permits are required, and no weight bearing walls are affected. In this latter case, the Technicians work from the specifications prepared by the Engineer. The Technicians support the Team by finding qualified vendors, obtaining quotes or prices, and preparing data to speed purchasing process. The Technician is very involved in setting up and trouble shooting the AT equipment provided in the program.

The VR process is the Counselor refers a client's case to AWTS, where the Technologist is the first contact. The Technologist schedules an assessment, after which the AWTS staff person conducting the assessment prepares the AWTS Report and meets with the Counselor. The AWTS Report is usually a compilation of data from the different team members involved in the referral. The Report contains the results and analysis of the assessment, and the recommendations for the AT intervention. A time and cost estimate is part of the recommendations. Approximately 90% of AT devices provided are available commercially; occasionally a device is modified for a client and rarely is a device custom designed and fabricated. The latter is primarily due to the lack of facilities for fabrication. The AWTS Report is presented to the Counselor and usually discussed at a work team staffing. After approval by the Counselor, the AWTS staff implements the planned intervention. Often, the plan is conducted in stages, for example, a residence modification when the client is first discharged from a primary medical facility, followed by ADL or training assistance and possibly vehicle modifications and then work-site accommodations. This means a client may be an active AWTS referral for many months, and possible years if post-secondary education is part of the VR client's work plan. The AWTS also is involved in marketing VR services to prospective and current employers of VR clients. This usually involves ADA assessment of the facility and a task analysis of the job proposed to determine what accommodations may be needed for a VR client.

## DISCUSSION

The AWT program is serving a large number of people with disabilities with AT services. The program is evaluating both structured assessment guides and outcome measures instruments. The goal is to determine the most appropriate measuring service delivery impact and effectiveness. An overview of the assessment guides and outcome measure instruments will be presented.

Data will be presented on the types of services and costs involved. In general, the funding is distributed 25% for vehicle modifications, 25% for residence modifications, 20% for computers and related devices, 15% for AT for people with Visual Impairments (including computers), 10% for mobility and 5% miscellaneous. However, the distribution of time for service delivery is 25% for travel, 20% for assessment, 15% for Report preparation, 13% for researching for appropriate AT devices and procurement procedures, 10% for AT Equipment installation/construction, 7% contractor monitoring, 5% consulting with Counselor and VR team and 5% marketing.

The time distribution reflects the use a virtual office in that the AWTS Team goes out into the community to conduct service delivery. This is evidenced by travel being the major time category. The time spent on assessment is indicative of the professionalism practiced by the OTs, Engineers and Technologists on the Teams. Overall, the time is divided 62% for actual service delivery and 38% for administrative functions.

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## REHABILITATION SERVICES AT THE NATIONAL REHABILITATION CENTER OF MEXICO

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### ABSTRACT
A new National Rehabilitation Center has been established in Mexico. The Center incorporates three existing National Institutes. The New Cente" will provide orthopedic, rehabilitation and communication services to the general population. The Center also incorporates the first Rehabilitation engineering Laboratory in the country. This paper describes the services the new center will provide as well as the challenges that it will face.

### INTRODUCTION
Rehabilitation Services in Mexico have been delivered by numerous providers of socialized medicine as reported by Letechipia (1). Although in principle each socialized medicine provider serves a segment of the population, services have been fragmented at best. Organized Rehabilitation Engineering services have been non existant. Assistive technology providers are limited to very small businesses (2). These businesses almost exclusively fabricate devices one at a time, resulting in hand made, non uniform devices for which service, parts and maintenance are rarely available. People with disabilities have been requesting the implementation of better rehabilitation services and the availability of appropriately priced assistive devices.

Responding to the needs of people with disabilities in Mexico, the Secretary of Health (Secretaria de Salud) planned and implemented a new National Rehabilitation Center (Centro Nacional de Rehabilitacion, CNR) The CNR was recently inaugurated and it represents a new approach in the provision of rehabilitation services in Mexico. The CNR has been implemented with the vision of making it a central point of the rehabilitation services in the country. The CNR brings together three recognized National Institutes of Health in Mexico. The National Rehabilitation Medicine Institute (Instituto Nacional de Medicina de Rehabilitacion), The National Orthopedics Institute (Instituto Nacional de Ortopedia) and the National Institute of Communication (Instituto Nacional de la Comunicacion Humana). The CNR is located in Mexico City.

### SERVICES
The services that the CNR offers include Rehabilitation , Orthopedic, Communication and Rehabilitation Engineering. A brief description of these services follows.

Rehabilitation Services

The main rehabilitation services include: Medical rehabilitation, Physical and Occupational Therapy, Vocational Rehabilitation, Orthesis and Prosthesis, and rehabilitation hospitalization. Some examples of the clinical programs include spinal cord injury program, cardiac and respiratory rehabilitation program, stroke program and multiple disabilities program.

Orthopedics Services
Services include full trauma and surgical procedures. Some areas of specialization include: bone tumor surgery, spinal cord surgery, hip, knee, and shoulder replacements, arthroscopy and sports medicine, hand surgery and multiple treatment programs.

Communication Services
Services include speech and language therapy, audiology services, ear, nose and throat medicine, including cochlear implants and measurement of evoked potentials. In addition numerous clinical and preventive programs are in place.

Rehabilitation Engineering Services
The Rehabilitation Engineering services will encompass five programs including the following:

- Assistive Technology Program.
  The goal of this program is to design and develop appropriate assistive devices.
- Gait and Movement Analysis Program.
  The goal of this program is to study movement and assess the effectiveness of surgical procedures. Also it will provide support to the prescription of prosthesis.
- Vocational Rehabilitation Program.
  The goal of this program is to assist in the reintegration to the labor force of persons with disabilities.
- Research Instruments Program.
  The goal of this program is to design new devices in support of biomedical and orthopedic research
- Biomechanics Program.
  The goal is to assist in the development of new orthopedic devices.

Also the CNR has an active educational program that includes the Orthopedic Residency and the Physical and Occupational Therapy and Orthosis and Prosthesis Programs. In addition an active research program is in place. Research areas include: genetics, biochemestry, cellular therapy, tissue engineering, bone pathology, physiology and sports medicine.

## DISCUSSION

Bringing the three Institutes under one roof provides numerous advantages to the consumer. It becomes a one stop shop, from the surgery to the completion of the rehabilitation process. It provides them with the first Rehabilitation Engineering services in Mexico.
The new CNR will bring to people with disabilities in Mexico the possibility of procuring first class medical therapy and rehabilitation engineering services.

The challenge for the medical providers will be to truly integrate their services and to promote interdisciplinary approaches to the treatment and rehabilitation of persons with disabilities. Also their challenge is to invest and support applied research to address the needs of persons with disabilities in Mexico.

The challenge for the Rehabilitation Engineering services will be to develop appropriate devices and transfer them to the small number of assistive technology businesses. Also to assist these businesses in becoming more productive and complying with international standards.

The challenge to persons with disabilities will be to access the services and to promote their expansion to other cities in the country.

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# AN ONLINE RESOURCE DESCRIBING THE EXPERIENCES OF A GROUP OF ASSISTIVE TECHNOLOGY CONSUMERS WITH QUADRIPLEGIA

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## ABSTRACT

A new assistive technology information resource is under development for individuals with high-level spinal cord injuries and the professionals that provide them with services. Unlike many of the excellent resources already in existence that contain details of product choices, this resource focuses on consumer perceptions of assistive devices and the process for acquiring them. At this point, the resource is still under development, but general themes in consumers' descriptions of their experiences are becoming apparent.

## BACKGROUND

Assistive technology is an important part of life for most individuals living with high-level spinal cord injuries. Accessible computers, adapted vehicles and a variety of other assistive devices offer independence in important tasks like communication, transportation and activities of daily living. The theoretical benefits are obvious. However, the reality of finding and acquiring useful, reliable assistive devices can prove a significant challenge for many. In general, consumers must be prepared to research, choose, negotiate, justify, purchase, install, master, maintain, repair and eventually replace most devices they need.

Interest in evaluating the outcome of assistive technology service delivery has increased dramatically in the last decade (1,2,3), partially because of reports of devices being abandoned (4,5). Along with outcome measure development, researchers have used qualitative methods to gain in-depth understanding of consumer experiences with assistive devices (6,7,8,9). These qualitative studies have documented the diversity of issues that can influence the effectiveness of assistive devices. Many of them advocate for better information sharing between consumers, service providers, developers and researchers around the "real-world" impact of particular assistive technologies and the services that provide them.

## OBJECTIVE

The purpose of this project is to develop and disseminate an information resource on consumer experiences with assistive technology in the years following a high-level spinal cord injury. This resource, called the Spinal Cord Injury Peer Information Library on Technology (SCI PILOT), aims to present stories, advice, strategies and homemade inventions as a kind of "virtual peer support" for other consumers, and as a source of in-depth consumer feedback for service providers. The resource will be published in multiple formats for accessibility, including the world wide web. A preliminary version of the resource is online at www.scipilot.com.

## APPROACH

SCI PILOT is being produced through a multi-stakeholder process based on qualitative research methods. The basis for the resource is the described experiences of approximately 30 assistive technology users with quadriplegia living in six locations in the United States and Canada. The process starts with a face-to-face meeting between the participant and an interviewer from the project team. The interviewer asks open-ended questions about the participant's experiences and perceptions of assistive technology, and collects photographs and video clips of the technology in use. Each interview is transcribed and analyzed by a group of five project staff, all with different backgrounds in assistive technology. Based on this analysis, a writer produces a summary of the individual's experiences, pulling salient quotes from the transcript. A second panel of consumers and service providers reviews each draft summary for relevance and presentation quality. Finally, the original participant reviews his or her summary for accuracy before it is included in the resource. In order to protect confidentiality, all names are fictitious.

## FINDINGS

At this point, the interviews are 75% complete and analysis is underway. The interviews show a great deal of diversity in participants' reactions to assistive technology, but strong, recurring themes are evident. Like McComas et al. (9), we find it useful to consider these themes in two main categories: (a) perceptions of the technology itself and (b) perceptions of the service delivery systems that supply the technology.

Consistent with Scherer's findings (6), the quality of the "fit" of a device in a person's life depends on a large number of factors relating to the user, their environment and the device itself. Consumers are only willing to invest their time and energy on devices that offer a clear benefit in accomplishing goals that matter to them. Devices must also be acceptable on a number of other levels, including the image that they present to others. Many participants articulated a kind of tug-of-war between function and image, but the relative importance of each varied from person to person. A common example is the choice that some individuals with arm function must make between using a manual or power wheelchair. One power wheelchair user with a C6 level injury said, "I do not really care what people think anymore. And you know, it is me who is left at the end of the day with enough energy to do as I please."

When participants were asked about assistive technology acquisition, they often described a long-term learning process, both in terms of gaining a better understanding of their needs, and in learning to negotiate with service providers around funding issues. During rehabilitation, purchase decisions are heavily influenced by service providers. Participants often felt that in these early days, neither they nor the providers had enough understanding of what their needs would be in the community. The low level of satisfaction that often resulted from these purchases provided motivation to become more knowledgeable and assertive in subsequent interactions with the service delivery system. This process is consistent with a model proposed by King (10) where the relationship gradually moves from a state of higher dependency on the recommendations of rehabilitation service providers to one in which consumer and service provider work in partnership, with the consumer taking on more control and responsibility for decisions. When asked to give advice for new consumers, participants often recommended that individuals do their own research and weigh their options carefully. As one experienced (23 years) consumer put it, "...every injury is different, every individual is different and you have to find things that'll work for that particular person.... I think the first thing for anyone that's going to need assistive technology, whatever kind it is, would be not take the first thing that comes along. Because there are people out there, whether they're in vocational rehabilitation or on the used-car lot, they'll try to sell you whatever they have at the moment. And so, the first thing is to take your time and look around to see what is available that might meet your individual needs."

## DISCUSSION

The stories in SCI PILOT demonstrate what a complex, long-term pursuit assistive technology can be for consumers. The resource is meant to help new consumers develop and refine their own strategies for dealing with assistive technology by detailing what other consumers have done. SCI PILOT also provides an additional source of information for service providers, developers and funders in their ongoing pursuit of client-centered practice.

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# ASSISTIVE TECHNOLOGY COLLABORATIVE FOR COMMUNICATION

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## ABSTRACT

Northeast Ohio has a variety of agencies serving people with disabilities that have responded in their own way to the increased demand for assistive technology services. Four of these agencies have formed a collaborative to share staff and material resources to more completely serve people with disabilities requiring assistance with communication and computer access. Given the wide range of assistive technologies, their cost, and the staff training required, the agencies as a collaborative can serve a greater number of people more effectively than any agency by itself.

## BACKGROUND

The four agencies participating in the Assistive Technology Collaborative are Cleveland Hearing & Speech, the Cuyahoga County Board of MR/DD, the Cuyahoga Special Education Services Center, and United Cerebral Palsy of Greater Cleveland. Based on the types and numbers of referrals each of the individual agencies were receiving, they recognized gaps in either the population of people it served and in the resources available to it. The population that the Collaborative had hoped to target included adults who had acquired disabilities, people in long-term rehabilitation centers, and residents outside Cuyahoga County. Grants from the Cleveland Foundation and the Eva L. & Joseph M. Bruening Foundation were obtained to purchase equipment and to fund the human resources necessary to operate the project.

## OBJECTIVE

The intention of the Collaborative is to provide information, evaluation, and intervention services to people who would benefit from the use of augmentative communication or computer access equipment and from the team of professional staff from each of the four agencies. Additionally, these agencies will benefit from the combined collection of information regarding emerging technology and public policy.

## METHOD

The direct service staff involved and their qualifications and roles are as follows:

- Cleveland Hearing & Speech is providing a SLP to serve and coordinate the needed services and supports.
- The Cuyahoga County Board of MR/DD is providing a SLP to provide service and coordinate the administrative work of the Collaborative.
- The Cuyahoga Special Education Services Center loans equipment and provides consultation for those students in schools in Cuyahoga County.
- United Cerebral Palsy is providing an ATP and a pediatric OT and PT for consultation and service provision as needed.

United Cerebral Palsy also acts as fiscal agent, provides clerical staff to conduct consumer intake and manage inventory, and houses the equipment purchased from the grant specifically for the Collaborative.

There were two paths taken to initially market the Collaborative to people and other agencies. Promotional booths were set up at three different local conferences with audiences of both technology consumers and service providers. Also, a mailing was sent out to about 300 agencies, hospitals, schools, colleges, and disability centers followed by a phone call within the week. A number of these entities received additional information through the phone conversation and a few requested and were then given a presentation describing the various services that could be provided.

A Collaborative referral can be generated from any source, including the partner agencies. If a partner agency decides to use Collaborative resources available, then they will coordinate the service provided. Typically, a referral will be generated from a rehabilitation facility, hospital, school district, or other agency or individual. In this case, they would first call United Cerebral Palsy and this intake information is then given to the service coordinator and finally to the appropriate team member. The service delivery team meets as a group at least monthly to review the status of the caseload.

## SERVICE DELIVERY

The initial goal was for 25 clients to be served the first year, 100 by the second and 200 by the third. These numbers were based upon the trends of referrals received by each of the partner agencies, then included projected referrals from new sources after the marketing and delivery of the service. Some of the consumers will only require information and simple referrals regarding assistive technology products, although it was anticipated that the majority would require more direct service. With the shared inventory of the Collaborative, any assessments necessary can be done with a wider range of materials and equipment. The Collaborative is also better able to loan equipment for an extended period of time. Finally, intervention services can be provided on a longer-tem basis to train consumers and partners on the use and care of the selected assistive device.

## RESULTS

Service delivery for the Collaborative began in July 2000. From that point through the beginning of December 2000, a total 62 people have been referred to the Collaborative for assistive technology service. Of these 62 consumers, 20 have cerebral palsy, 15 were diagnosed with Amyotrophic Lateral Sclerosis, 10 fall into the broader developmental disability category, and the balance includes people with stroke, acquired brain injury, multiple sclerosis, cancer, and people who have required a tracheotomy. Forty of these consumers reside outside Cuyahoga County. A breakdown by age finds 15 of these people over 61 years of age, 12 and between forty and sixty years old, only 5 between twenty and forty, which leaves 30 consumers at less than twenty years old. A school system and a developmental center, both outside Cuyahoga County, have referred over half of these younger clients. Many people required some degree of research, assessment, or trial of equipment as fewer than ten needed simple information or linkages. Finally, a consultation was also given to an assisted living facility that had received a grant to create a small computer center for their elderly residents.

## DISCUSSION

The Assistive Technology Collaborative has certainly met and exceeded the projections it set for itself. The initial set of resources, both staff and equipment, has needed to be fully realized more quickly than anticipated. These issues are continually being addressed. Most importantly, though, the Collaborative is providing services to people were not receiving services through any single partner agency. For example, the communication devices purchased have helped enhance the service provided to people with Amyotrophic Lateral Sclerosis. Also, the shared staff have been able to recommend equipment to younger students outside Cuyahoga County. The Collaborative has been pleased to help increase the service provision in Northeast Ohio to people requiring assistive technology.

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## Preparing Special Educators with Technology Competencies

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**ABSTRACT**

This paper describes an introductory course in special education technology for pre-service teacher education students. The course objectives were updated to address state mandated instructional technology competencies for teacher licensure and consider nationally recognized guidelines for the preparation and professional development of special educators. A primary goal of the course was to prepare class participants with the knowledge, skills, and attitudes for applying technology in educational settings. Course objectives, format, content, and experiences are discussed to highlight ways that assistive technology competencies were woven into the fabric of an instructional technology course.

**BACKGROUND**

Many states have adopted technology-based competency standards for instructional personnel. Typically, the basic knowledge and skills required of licensed professionals are designed to complement technology standards established for students. At a national level, the International Society for Technology in Education (ISTE) has published educational technology standards for students (NETS) and more recently the National Educational Standards for Teachers (NETS-T) which focus on the fundamental concepts, knowledge, skills, and attitudes for applying technology in educational settings (1).

Preservice and practicing special education teachers need to be prepared to apply educational technology effectively complemented by competencies in the use of assistive technology (2). As a part of its work in establishing statements to serve as competencies for special educators (3), the Council for Exceptional Children compiled a set of essential knowledge and skills statements for assistive technology competencies (4).

Many teacher preparation and professional development programs have implemented some form of training in educational technology to address certification and endorsement requirements. The University of Virginia has offered a graduate level course introductory course in instructional technology for special education teacher candidates for the last ten years.. Until recently, the class section designated for special education majors included some components that provided information related to assistive technology. For example, one class session was devoted to introducing adapted computer devices. The issue of specific technology-related standards and competencies indicated a need to review the course objectives and content to formally address specific areas of knowledge and skills.

**OBJECTIVES**

The primary purpose for this initiative was to enhance an existing class in special education technology . Specifically, course objectives were updated to reflect established standards for educational and assistive technology competencies. Other objectives included ensuring that course content would give students an understanding of universal design principles and the ways that assistive technology, used in special education, interfaces with educational technology, used for general instructional purpose. Providing students with a practical perspective on the use of assistive technology in educational settings was a priority in deciding on the experiences arranged during the semester.

## APPROACH

Students: A course in special education technology is offered each fall and spring semester. The twenty-four students enrolled during the semester discussed in this paper were enrolled in a five-year Masters in Teaching degree program with a major concentration in Special Education (Learning Disabilities, Behavior Disorders, and/or Mental Retardation). They had just completed a semester of student teaching and were in the final semester of their program. To accommodate resource and space limitations, the class was divided into two sections that met on different afternoons. The course content and experiences were the same for both groups.

Instructor and Guest Speakers: The author, a special educator, has been the instructor for this course for the past ten years and has also had considerable experience with training and staff development in the areas of instructional and assistive technologies. In addition, the author's full-time position is in a service delivery role as a technology coordinator / educational consultant in a children's rehabilitation center. Guest speakers were invited to address specific topics which included an introduction to the Virginia Assistive Technology System (VATS), an overview of "The Low Down on Low Tech AT," the roles of related service providers (e.g., occupational, physical, and speech-language therapies) on an assistive technology team, and a discussion of funding and policy issues related to assistive technology. The class also took a field trip to the University library for an orientation to the electronic text center and to see adapted equipment for library users.

Environment: Most of the classes were held in the Technology Resource Center (a computer lab with adaptive equipment) at the children's rehabilitation center. This arrangement generated secondary effect of exposing students to various assistive technology users and their devices that they encountered en route to the computer lab.

Course Objectives: The course description and objectives were defined to directly incorporate standards-based concepts and skills in educational and assistive technologies. The *Virginia Technology Standards for Instructional Personnel* were also followed closely. Specific areas addressed included: social, ethical, legal, and philosophical issues; technology operations and concepts; teaching, learning, and curriculum; planning and managing the teaching and learning environment; assessment and evaluation; productivity and professional practice; and communication and collaboration.

Course Content: Course topics covered use of productivity tools (paint/draw programs, spreadsheet, database, and slide show), software evaluation, the Internet (search strategies, integrated lesson planning, web page design including universal design principles, Multimedia (project development), adapted computer devices, assistive technology evaluation and consideration in the Individualized Education Program (IEP), and the presentations offered by the guest speakers described above. Four classes were devoted to working directly with children who attended an after school computer enrichment program. Adapted computer access and other assistive technology enabling tools were used by some of the participating youngsters.

Assignments and Evaluation: Graded assignments involved competency-based tasks that demonstrated acquisition and application of specific skills. For instance, on-line search strategies, web page evaluation, and database development were combined in an integrated task.. Students were expected to search for sites related to assistive technology, evaluate the sites based on specific criteria, and design a database to manage information about the sties. A multimedia project involved creation of an accessible electronic book or activity with HyperStudio. Students prepared and implemented lesson plans for the weeks when they worked directly with children.

Student Self-Rating: On the first day of class, students were asked to fill-out a survey to self-rate their current level of expertise, from "novice" to "expert" in various areas of educational technology. They also completed an ungraded "preview quiz" to asses their knowledge of assistive technology terms, devices, and services. In general, most students reported familiarity (at least a "beginner level") with productivity tools, e-mail, and the Internet. Most students considered themselves a "novice" or "beginner" with multimedia applications and development. Results of the "preview quiz" indicated a minimum knowledge base related to assistive technology. Also, the responses from many students suggested the perception that assistive technology is for individuals with severe physical limitations. During the last class, students were again given the opportunity to rate their technology and re-take the ungraded assistive technology quiz.

**DISCUSSION/RESULTS**

All students completed the course and successfully demonstrated the required competencies through assignments and projects. Results from the pre- and post-course self-ratings showed that students believed that they had gained or refined their technology skills and moved to an "experienced" or "expert" level in all areas. The follow-up quizzes indicated skill development in the use of specific devices and a heightened level of awareness related to assistive technology resources and issues. A shift in perspective was also noted with more students able to articulate assistive technology needs and solutions for individuals with cognitive and behavioral difficulties.

The established objectives for enhancing the course by updating syllabus objectives and content were achieved. A fourteen-week course can only offer introduce students to the technology-related concepts and skills that they will need in the classroom. Incorporating specific assistive technology competencies prepares special educators for confronting the instructional and legal demands they'll encounter. Establishing a fundamental level of proficiency in the use of technology tools and understanding of issues will serve an in initial step in preservice and practicing teachers' continuing professional development in the field of special educators.

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## PROBLEM-BASED LEARNING FOR ASSISTIVE TECHNOLOGY EDUCATION

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### ABSTRACT

This paper presents a problem-based learning (PBL) strategy used successfully to teach Windows accessibility features, one aspect of assistive technology content, to preservice students in a professional training program. This PBL strategy can be replicated for any student learning Windows accessibility features.

### BACKGROUND

Although most professional preservice education was designed primarily around a traditional instructor-centered approach (consisting of lectures and providing a needed focus on content), graduates sometimes had difficulty generalizing their knowledge to real world contexts. As a remedy, many medical schools have adopted PBL, an educational strategy that places emphasis on the learner, to develop entry-level practitioners with strong abilities in the areas of critical thinking, problem-solving, communication, teamwork, self-direction, and lifelong learning.

According to Barrows as cited in (1), the core of PBL consists of the following characteristics: learning is student centered, learning occurs in small groups, teachers are facilitators or guides, problems form the organizing focus and stimulus for learning, problems are a vehicle for the development of problem-solving skills, and new information is acquired through self-directed learning. Harden and Davis (2) propose a learning continuum, beginning with traditional information-based, teacher-centered learning (no PBL) and progressing toward increasingly more student-centered, PBL tied to real situations. This continuum includes 11 learning approaches (examples are listed in parentheses): (a) theoretical (traditional lecture, textbook), (b) problem-oriented (lecture with protocols or guidelines), (c) problem-assisted (lecture followed by practical experience), (d) problem-solving (case discussions), (e) problem-focused (lecture with study guides), (f) problem-based: mixed (student opts either for information-based or PBL), (g) problem-initiated (problems used to interest students in a topic), (h) problem-centered (text provides series of problems followed with information to solve problems), (i) problem-centered discovery (principles derived by students from their work), (j) problem-based (information from one problem generalized to another), and (k) task based (problems solved in real time in the clinical setting).

### OBJECTIVE

At one midwestern university, the objective was twofold: to analyze the existing method of providing assistive technology content and to determine a more effective approach of teaching one aspect to preservice students in a professional training program.

### APPROACH

Analysis determined the existing primary method of providing assistive technology fell along the traditional, instructor-centered end of the learning continuum; specifically, (a) theoretical and (b) problem-oriented approaches. The aspect of current assistive technology content, Windows accessibility features, was selected for redesign with a PBL strategy because of immediate availability—students are required to own computers in this curriculum.

## RESULTS

In keeping with PBL, the case study or problem (sometimes called *trigger*) is presented before content, providing structure for learning and allowing students to construct their own knowledge. The following is the redesigned educational strategy for Windows accessibility features.

You just landed a job with ADA Solutions, Inc., a company that contracts to area businesses, providing consultation for physical and electronic accommodations for persons with disabilities. Your company offers team consultations for businesses desiring a holistic approach to office accommodations and also provides individual consultation. Your team will consult to At Your Service, Inc. in the first problem and you will consult alone to the individuals in the second problem. For both problems, all computers owned by the company and individuals run Windows 98 and Microsoft products. You and your team are well aware that computers using Windows 2000, 98, and 95 have built-in accessibility features. To customize each computer, you know that all you have to do is press the <START> button on the monitor screen (or special Windows key on the computer keyboard) for a pop-up menu, and you have two choices: (a) select *Settings*, select *Control Panel*, and double-click on *Accessibility Options* or (b) select *Programs*, select *Accessories*, and select *Accessibility*. (Hint: You will need to work within each of the two choices to determine all the appropriate features.) You are pleased to find computers with Internet access because you know that if your team gets stuck—either forgets a particular feature or cannot find something—you can easily find what you need and more on Microsoft's webpage www.microsoft.com/enable. You also know that your job is fairly easy with Windows 98; however, if the company had other computer systems, your team also knows that Microsoft has similar accessibility features available in *AccessDOS* for DOS computers and *Access Pack* for Windows 3.x at www.microsoft.com/enable/products/archives.htm. And if these facilities were Macintosh-based companies, you also know that Macintosh computers have had *Easy Access* with similar accessibility features built into the operating system for a long time.

Problem A. At Your Service, Inc., a local company that offers short-term word-processing on an as-needed basis, just hired several persons with disabilities. Realizing that under ADA Title I the company must provide accommodations for employees with known disabilities, Matthew Backsen, the owner, contracted with your team to provide accommodation recommendations. When you consult to At Your Service, Matthew Backsen introduces you to his six employees: Sam, Jacob, Emma, Jack, Martha, and AJ. For each person, determine the accessibility feature(s) needed and justify your selection. Unable to use his fingers, Sam uses a headstick to access the standard keyboard successfully except he cannot use a standard mouse and he cannot press more than one key at a time (e.g., pressing <Ctrl> <Alt> <Del> at the same time to reboot the computer). Jacob, who has been deaf since birth, gets angry because he always gets information last: he cannot hear the beep made by the company email system when a new message is delivered. Although Emma has athetoid movements, she can speed up her movements to use a standard keyboard, but sometimes drags her fingers across extraneous keys, making a jumble of letters. Her computer has already been adapted with a trackball, which Emma can use easily. Jack complains of "mouse problems": he has trouble finding his cursor, the mouse moves "too fast," and he cannot tell which direction the mouse is moving. Martha has difficulty seeing the standard screen. For her, the "pictures" that indicate the programs are too small, the scrollbars too narrow, and the color makes reading difficult. Additionally, she also does not know when she has already hit a locking key such as <Caps Lock>. AJ has difficulty with people not understanding him so he uses an augmentation communication prosthesis—he wants to access the computer via his communication serial device rather than through the standard keyboard.

Problem B. Although accessibility packages, available in Windows and in the Macintosh operating systems, were originally designed for people with disabilities, you know these accessibility features can be utilized by just about anyone. ADA Solutions, Inc. sends you alone to consult to the following five computer users: Irene, Jon, Sandy, Martin, and Ernie. For each person, determine the accessibility feature(s) needed and justify your selection. List three features to adapt the current computer system without cost for Irene, who swears her bifocals make her dizzy. Determine two no-cost solutions for Jon, a sports reporter who is used to pounding with the two-finger method on manual typewriters, resulting in restarting difficulties—AKA soft start, rebooting—and repeating key strokes because of his heavy "hand." Decide on a free solution for Sandy who finds the touchpad (i.e., pointing device) of her laptop computer to be sluggish. Activate two zero-cost accessibility features for Martin who often works with his hearing aids turned off because he is distracted by noise but believes his computer productivity has decreased. Determine two no-cost solutions located within this operating system for Ernie, who constantly misplaces the cursor on the screen.

Accessibility Feature Solutions (Problem A or B)

| | | | |
|---|---|---|---|
| BounceKeys/FilterKeys: | Sam/Emma (A), Jon (B) | Mouse Trails: | Jack (A), Ernie (B) |
| Color Settings: | Martha (A), Irene (B) | Scroll Bar: | Martha (A), Irene (B) |
| Cursor Size: | Jack (A), Ernie (B) | SerialKeys: | AJ (A) |
| Icon Size: | Martha (A), Irene (B) | ShowSounds: | Jacob (A), Martin (B) |
| Magnifier: | Martha (A), Irene (B) | SoundSentry: | Jacob (A), Martin (B) |
| MouseKeys: | Sam/AJ (A), Sandy (B) | StickyKeys: | Sam/Emma (A), Jon (B) |
| Mouse Speed: | Jack (A), Ernie (B) | ToggleKeys: | Martha (A), Irene (B) |

## DISCUSSION

The redesigned educational strategy for Windows accessibility features falls along the PBL end of the learning continuum. Compared with the initial teaching approach, the first problem (students discovering knowledge as a group), moved 7-8 rankings toward PBL to (i) problem-centered discovery while the second problem (individual students demonstrating generalization of knowledge in a testing situation) moved 8-9 rankings toward PBL to (j) problem-based.

According to Edens (1), PBL provides opportunities for students to make a direct link between theory and practice, between "knowing that" and "knowing how," with students learning how to apply inert knowledge to problems that they are likely to encounter in their professional career. For this midwestern university, PBL became a more effective approach of teaching one aspect of assistive technology to preservice students in a professional training program.

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# TEACHING SEATING AND WHEELED MOBILITY PRESCRIPTION: A RANDOMIZED CONTROLLED TRIAL OF FOUR INSTRUCTIONAL METHODS

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**ABSTRACT:**

The appropriateness of a consumer's seating and wheeled mobility system varies considerably depending on the competence, proficiency and experience of the professionals assisting the user [1-3]. The purpose of this study was to compare the effectiveness of four educational interventions (self study, workshop, internship or combination) to determine which one is most effective in elevating the knowledge of entry-level physical and occupational therapy clinicians. Results showed no significant change in pre/posttest score in relationship to the type of intervention (p= 0.488). However, total hours of training compared to the change in pre/posttest score were found to be significant (p= .047).

**BACKGROUND:**

The competence, proficiency and experience of therapy professionals evaluating and prescribing wheelchairs and seating systems vary considerably[1-3]. A well-fitted seating and wheeled mobility system promotes a more functional posture, enhancing independent mobility, improving comfort and decreasing the risk of pressure sores and postural deformity [1-5]. However, the availability of physical therapists (PT's) and occupational therapists (OT's) experienced and or specially trained to provide seating and wheeled mobility prescription is limited [3, 6]. Many feel that targeted professional training will maximize the consumer/technology match [1,2,6]. A review of the literature has not revealed any research about the most effective means to increase the level of competence and proficiency for professionals in the area of seating and wheeled mobility prescription.

The purpose of this study was to determine which educational intervention (self study materials, workshop, internship or combination) would best elevate the level of expertise of the entry-level clinician, in the prescription of seating and wheeled mobility systems. The results can help guide the future training of assistive technology (AT) professionals.

**METHODS:**

Second year masters and senior level bachelors PT and OT students from three universities were invited to participate in this study to receive supplemental specialized training for prescribing wheelchairs and seating systems. 37 students volunteered and 20 students were randomly selected (10 each PT and OT). The students were randomized into one of four training groups utilizing a stratified randomization process to equally distribute PT and OT students with equal representation from the three universities. The training groups were as follows: 1) self study (written materials and videos, approximately 15 hours to complete); 2) self study and attendance in an eight-hour workshop; 3) self study, attendance in an eight-hour workshop and two days of small group observation in a wheelchair service delivery program; and 4) self study and two days of small group observation in a wheelchair service delivery program. All subjects gave written informed consent prior to participating.

A pretest was administered prior to subject group assignment. The pretest consisted of viewing a videotaped seating and wheeled mobility evaluation and completing an assessment form. The subjects were asked to identify the problems, goals, and recommendations for the client presented [1, 7, 8]. Upon completion of the study intervention, the subjects completed a posttest utilizing the same procedure.

The following pretest/posttest grading system was developed. A list of common seating and mobility problems, goals and equipment features was created by polling a group of "expert" clinicians. This list was used as a checklist to transfer the data from the subjects test sheets. The checklist sheet was then compared to a "gold standard" answer key of potential "correct" answers for each client example, created by two expert clinicians. A score for each subject was tallied to include a total for all correct, incorrect and missing responses.

The scoring system was tested for interrater and intrarater reliability and was highly correlated ($r^2 > 0.70$) with $p<0.05$. Two independent scorers blinded to group assignment graded all pretests and posttests. Significance level was set at 0.05. Pre and posttest scores were first compared using a paired t-test. Then, change scores were created by subtracting posttest scores from pretest scores. Analysis of variance (ANOVA) was used to determine if any significant differences existed between the four groups and the change scores. To determine if there was a relationship between hours spent in study versus change in score, correlations were completed.

**RESULTS:**

The twenty subjects had a median age of 24.5 with a range from 22-48 years. 85% of the subjects were female and 15% were male. There was no significant difference between groups with respect to age, gender, discipline and university.

Since the interrater scores were highly correlated the average of the two scorers was calculated and used to determine the difference between the pre and posttests resulting in a change in the grand total (cgt). The results showed no significant difference ($p= 0.488$) in cgt between training groups.

The total number of hours of training was significantly related to change in test score ($r^2=0.612$). As the number of hours increases the change in correct grand total score between the pre and posttest is improved. Hours of training were significant ($p= 0.047$) between the four groups, with group three having the highest average of hours ($24.6 \pm 4.8$).

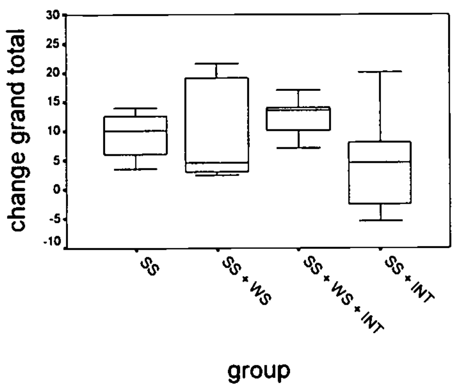


Figure 1. Mean change in grand total score between pre/posttest score for four educational intervention groups. SS=self-study, WS=workshop, INT= internship

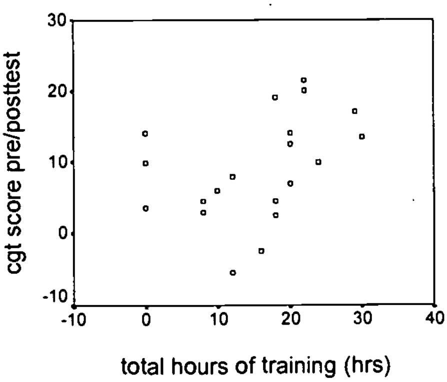


Figure 2. Change in grand total score between pre/posttest scores in relationship to total hours of training

## DISCUSSION:

This study examined the relationship between the type of educational intervention and the wheelchair seating and mobility prescription of entry-level PT and OT clinicians. The quality of the prescription was calculated by taking the difference between the pre and post-tests scores of two sample patient evaluations.

Results from this pilot study suggest that the type of intervention may not be as influential on impacting the quality of wheelchair seating and mobility prescription as the total hours of education. These results should be interpreted cautiously as the length of each educational intervention (weeks for self study, hours of workshop, and length of internship) may not have been adequate to demonstrate a difference between interventions and the sample size was small. The development of a scoring system to interpret the pre/posttest scores was found to correlate for two independent scorers. In the future this scoring system may be applicable to other studies testing educational interventions related to assistive technology.

Future studies will be needed to determine if in fact educational interventions impact on the quality of wheelchair seating and mobility services to the consumer.

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# MULTIDISCIPLINARY POSTGRADUATE EDUCATION IN ASSISTIVE TECHNOLOGY: CHALLENGES AND OPPORTUNITIES

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## ABSTRACT

There is a growing recognition that a multidisciplinary approach to Assistive Technology provision is required in order to produce effective rehabilitation services. While Assistive Technology professionals may work with the same patients, they work with professional colleagues whose approaches are different. They may therefore need training to help them move towards a more integrated and collaborative approach. This paper will explore the opportunities and challenges that multidisciplinary postgraduate courses in Assistive Technology may face. Features of a newly developed Masters in Assistive Technology at Kings College, London will be used to illustrate these opportunities and challenges.

## BACKGROUND

It is generally accepted that AT is a shared concern of all those in who work in the rehabilitation field. [1] AT is an "eclectic interdisciplinary field, drawing on the insights and expertise of many professionals and other personnel" [2]. Whilst lots of different professionals might play a role in AT provision, they are not always working together. For example researcher have found that AT services in the UK are often fragmented which has lead to confusion and gaps in provision and can adversely affect the AT user. They conclude that in order to be successful, AT should be introduced to the user as part of a holistic rehabilitation strategy [3], in which the AT user collaborates with a number of services/agencies, involving people of different disciplines. The collaboration, communication and co-ordination of effort by a rehabilitation team working with a person with a disability is therefore essential for effective service delivery [1].

Rehabilitation professionals therefore need to learn how to collaborate and communicate with one another. This suggests a role for multidisciplinary education. Multidisciplinary education generally involves students from different professions sharing learning of common curricula and/or learning about the contribution of each team member through shared activities such as group work. [4,5]. The timing of multidisciplinary education is often critical. Some argue that students can be unable to participate as team members until they have learned the basic skills of their own discipline [6]. This might suggest that multidisciplinary education has more chance of success at a postgraduate level, after students have gained their basic undergraduate training.

## OPPORTUNITIES

At an undergraduate level, some of the benefits of multidisciplinary education for health professionals have been identified as enabling students to become competent team workers, improving communication between team members and bringing new ways of solving patients problems [4, 5]. It is possible to design postgraduate multidisciplinary education for AT professionals, so that it offers similar benefits. For example, if the philosophy of multidisciplinary teamwork permeates through all aspects of the course, from admissions through to assessment then students should recognise its importance. Educators can therefore work to ensure that a multidisciplinary mix of students are accepted on to a course, that they are taught by a multidisciplinary team, given opportunities to learn about teamwork as well as demonstrate competence in teamwork and communication skills. At Kings College, London students will be accepted onto the Masters course in Assistive Technology from a range of different disciplines and therefore with a range of qualifications.

Whilst the success of multidisciplinary education will depend to some extent on students recognising the importance of multidisciplinary teamwork, it will perhaps depend more heavily on students valuing such teamwork. Students are likely to value multidisciplinary teamwork if they can see the relevance to clinical practice and patient care. Educators can help students see the value and relevance of teamwork through the use of pertinent case studies, inviting AT users to speak about their experiences, and carefully chosen clinical placements. Perhaps more importantly, students can be encouraged to work together in order to identify new ways of solving patient problems. For example, for the Masters in Assistive Technology at Kings College, London the assessment for a module entitled "AT Provision" involves problem-based interdisciplinary group work. Students are required to work in groups and give a 30 minute presentation based on a given AT access case study. Tutors assess the group element of the presentation, while each individual contribution to the group work is peer-assessed.

## CHALLENGES

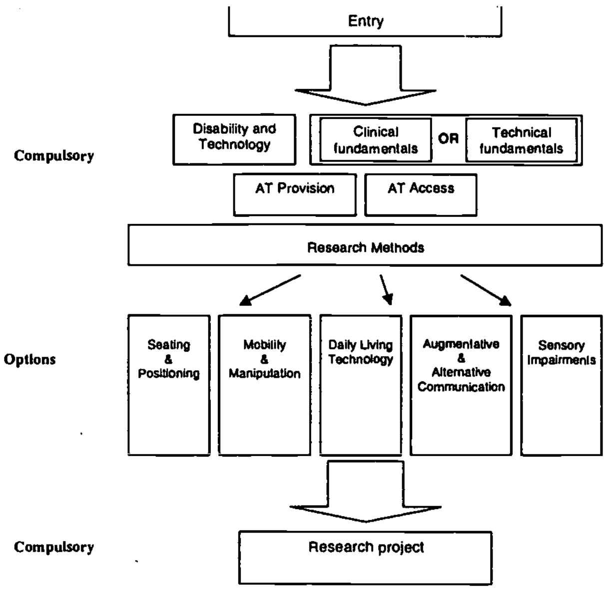
The challenges that face postgraduate multidisciplinary education in Assistive Technology include difficulty in deciding core curricula, the fear of rehabilitation professionals losing their identity and student attitudes. For any multidisciplinary course, conflict can be caused when trying to decide how much of the course should be taught to all students and how much, if any should be taught in separate discipline specific groups. For Assistive Technology, it is generally agreed that there is a lot of content that can be taught to all rehabilitation professionals. So for example, with the new Masters in Assistive Technology at Kings College, London all students will study four compulsory modules on AT Access, AT Provision, Disability and Technology and Research Methods. All students will also have the opportunity to study three specialist options from a selection of Seating and Positioning, Mobility and Manipulation, Daily Living Technologies, Sensory Impairment and Augmentative and Alternative Communication. However, in recognition that some students will enter the course with little clinical knowledge, while others will enter with little technical knowledge students will be required to study either a module on Technical Fundamentals or a module on Clinical Fundamentals (See Figure 1). The challenge for the course team will be to help the students see how these "separate" modules still contribute to a multidisciplinary learning experience.

At postgraduate level, students will probably have a clear sense of professional identity depending on the nature of their undergraduate studies. Whilst this may make them more open to exploring the role of other professionals within the rehabilitation and AT team, educators will need to be careful that students individual professional identity is not overly threatened and that they do not revert to "historic tribalism". For the Masters in Assistive Technology at Kings College, London a multidisciplinary team of lecturers have been brought together to deliver the course and include engineers, psychologists, physiotherapists, occupational therapists and rehabilitation consultants. The challenge for the lecturers will be to try and be "role models" for students and in their interactions with students help them see how each discipline can develop a professional identity that incorporates characteristics of a team worker without jeopardising unique discipline specific characteristics.

## CONCLUSIONS

- Rehabilitation professionals need to learn how to collaborate and communicate with one another in order to provide AT users with a holistic, integrated service
- Multidisciplinary education at a postgraduate level might provide these professionals with the learning opportunities they require
- Whilst multidisciplinary education at postgraduate level offers many opportunities there are also a number of challenges which educators need to address.

**Figure 1: Structure of MSc in Assistive Technology at Kings College**

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# DEVELOPMENT OF A GRADUATE-LEVEL CURRICULUM IN ASSISTIVE TECHNOLOGY: A 3-YEAR PROGRESS REPORT

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## ABSTRACT

There are numerous challenges faced by those developing university-based graduate programs in assistive technology (AT) and/or rehabilitation engineering (RE). The relative youth and niche status of the field have resulted in few previous efforts to develop bona fide graduate education and training curricula. In addition, the research challenges that face the fields of AT and RE, as well as the multi-disciplinary nature and breadth of practitioner roles, has precluded consensus on a uniform educational model. This paper discusses the developmental status of a relatively new graduate program in AT, including self-identified strengths, areas of needed improvement, and a reflective view of challenges that could confront others seeking to establish or modify university programs of their own.

## BACKGROUND

Lenker [1] provided a summary of paradigms in AT and RE education within the United States. RESNA has since established a web page [2] that summarizes currently available degree programs in AT and RE. Review of both [1] and [2] reveals that there is great variation in graduate-level educational models, reflecting the inherent diversity of the field in terms practitioner/researcher disciplines (e.g. engineering, occupational and physical therapy, speech-language pathology, special education, and architecture), intervention areas (e.g. seating and wheeled mobility, computer accommodation, augmentative communication, and ergonomic workplace accommodation), and reimbursement models (e.g. medical, educational, and vocational rehabilitation). Given the absence of a uniform approach to delivery of AT and RE professional education, it is important for graduate educational programs to continue presenting their programmatic models, successes, and failures in order for them to share their experiences in a manner that will promote evolution and growth of educational practices.

## PROGRAM GOALS

Our overarching programmatic goals were to offer a graduate-level curriculum in assistive technology that, although housed within the Department of Occupational Therapy, would appeal to clinicians from multiple disciplines practicing in the community, as well as graduate students from multiple departments across campus. The educational goals for students in this program would include acquisition of advanced clinical practice skills in AT, as well as development of an appreciation for the body of research literature relevant to various content areas. Programmatic permanency would be sought within the university structure in order to establish a program that was not dependent on extramural training grant funding for long-term survival.

## APPROACH

Support: Initial support was provided in 1997 through the Dean of the School of Health-Related Professions, who designated a full-time clinical faculty position within the Department of Occupational Therapy that would be dedicated to the task of program development and instruction.

Full latitude was given to the Program Director for all decisions about curriculum structure and individual course content. A five-year training grant was sought and obtained from the Rehabilitation Services Administration, US Department of Education, which has provided additional budgetary support for student stipends and sponsorship of guest lecturers.

Curriculum Structure: The curriculum includes six courses (*Computer Access I & II*, *Ergonomics and Job Accommodation* [3], *AT Outcomes Measures* [4], *Wheeled Mobility and Seating*, and *Rehabilitation Environments*) and a clinical fieldwork experience. One of the courses (Rehabilitation Environments) had been approved as a graduate course previous to initiation of this program. The other five courses were offered initially as 'special topics' courses, and four of these subsequently received university approval as permanent graduate courses. Permanent approval for the fifth course (Computer Access II) has not been sought, since funding for the instructor is contingent upon the RSA grant.

Faculty: The faculty roster includes three from the Department of Occupational Therapy and a clinician from our AT service delivery clinic. Two of the four have doctoral-level preparation and two have Master of Science degrees. The disciplines represented include occupational therapy, engineering, and program evaluation.

Instructional Methods: A mix of instructional methods are employed on a regular basis: didactic lecture, interactive class discussions of research articles, student presentations of projects, and lab experiences that focus on exposure to AT devices that are the tools of intervention strategies discussed elsewhere in lecture and homework readings.

Assignments: The nature of assignments and projects has included: critiques and suggestions for improvement of existing adaptive computing software; written critique of clinically-based outcomes studies from the research literature; development of a proposal for clinical evaluation of an adaptive software product with a specified disability population; development of a proposal for evaluating a particular intervention strategy or overall program of service delivery; and written evaluation of the accessibility of a consumer product or community-based kiosk.

## DISCUSSION

### Programmatic Strengths

- Offering semester-length courses that are topic-specific allows a fairly substantial treatment of the respective content areas, and it has been attractive to clinicians from the community and graduate students from other departments.
- Approval of the individual courses by the university's graduate school establishes a relative permanency of this content within the university's overall options for graduate coursework.
- Approval of the collection of courses as a 12-credit 'advanced graduate certificate program' lends programmatic stability and, with that, an additional level of legitimacy within the contexts of both University and State Education curriculum structures.
- Judicious incorporation of faculty from other departments on campus, including: human factors engineering, architecture, communicative disorders and sciences, and rehabilitation counseling.
- Development of students' professional skills through course assignments, including: poster presentations, written literature reviews, student-led class discussions, design projects, and submission of conference papers.
- Use of a blackboard with touch-screen capability [5] enables efficient demonstration of adaptive software in a manner that is amenable to presentation before medium-sized groups.

Challenges
• Tenure-track faculty were averse to a clinical faculty member having a significant role in program administration, curriculum development and instructional responsibility at the graduate level.
• Obtaining formal approval for graduate certificate status and endorsement from the University and State Department of Education required 20 months. Although the bureaucratic pathway may not be as circuitous for those residing in other states, this nonetheless speaks universally to the fact that formal program development takes time and one should budget properly for that time.
• Without the educational incentive afforded by having a formal Master of Science program (e.g. Rehabilitation Science with a specialization in AT), our ability to recruit students from outside the immediate geographic area has been hindered.
• Striking a balance between the 'how to practice' nature of advanced clinical content and the 'how to conduct research' mission of graduate education in a research-oriented university presents a constant philosophical tension.

Areas of Future Growth
• Development of a Master's degree option will be extremely important if we are to begin recruiting competitively for students outside of our immediate geographic area.
• None of our courses is currently offered via distance learning, which is, by far, the most common request that we receive.
• A standard set of goals and objectives for AT and RE clinical experiences is needed, both for our program and others like it elsewhere.

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# AN INTEGRATED INFORMATION SYSTEM FOR SEATING CLINIC SERVICE

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## ABSTRACT

An integrated information system is developed using commercial software to assist the operation of the seating clinic. This system is comprised of a database containing patient information, treatment records, seating assessment reports. Linked to each patient record, there is an associated visual database stored in CD-ROMs. These images and video clips help clinicians to review the conditions of the patients as treatment progresses. In addition, x-ray films are also stored so that surgeon can review patient's skeletal deformities during the clinic session. This information system also facilitates clinicians in performing researches, particularly in relation to treatment outcomes.

## BACKGROUND

The seating clinic and wheelchair bank in Hong Kong was established to provide a comprehensive seating and mobility service for children with neuromuscular diseases [1]. Traditionally, hospital patient records were stored according to the specific clinic that he/she attended which was associated to different hospital departments. For example, children with disabilities will have their assessment/treatment records in Pediatric Department, Orthopaedics Department, Radiology Department ...etc. Unfortunately, such filing system has posed difficulties in operation, as clinicians often have to reveal patient's complete medical history during a particular clinic session. In current practice, hardcopies of records have to be retrieved from various hospital departments prior to the clinic session, and sent back for filing after use. This process was inefficient and often clinicians were presented with incomplete records. In the seating clinic, we experienced great difficulties in trying to provide clinicians with complete patient records. In addition, the massive information collected in the patient's file from the seating clinic has also made data retrieval difficult. These information included detail seating assessments, picture records of patient's posture, x-ray films, interventions as well as outcome measurements that were performed from time to time.

## OBJECTIVE

The aim of this work is to develop an integrated patient information system which allows quick retrieval of patient's record in both text and multimedia format. Patients' medical history, including assessment results will be stored in a database. This database will be linked to a multimedia storage unit, which holds all related diagnostic films as well as other visual documentation.

## FEATURES OF DATABASE

The database was developed using commercial software: Microsoft Access 97, Structured Query Language (SQL), and Visual Basic for Application (VBA). The contents of the database included: general patient information, medical history, social information, functional skills and physical examination record. In order to ease clinicians in documenting the anthropometric data, and for equipment prescription purpose, an electronic form was incorporated to keep track of all body dimension changes. Also, a summary data sheet was used to record the patient's seating and mobility problems and the desired treatment goals. Clinicians could also specify queries using one or more selection criteria, and the database allowe easy retrieval of patients' records. Further, each of the patient's record was linked with a visual databank, which incorporated any pictures, video clips, x-ray films recorded from different dates of attendance. These images helped to document body deformities such as scoliosis and contractures, as well as comparison of body alignments resulting from seating interventions. Video clips provided dynamic information on body motions changes after seating and mobility equipment was provided. In addition, through video recordings, clinicians could assess whether there were any changes in the patient's ability in daily living (ADL).

With this information system, clinicians at seating clinic could be well served in the following aspects:

Clinical Application

During clinic session, clinicians could browse through patient's record and review the treatment history by simply entering into the relevant data files. For intervention, after the seating and mobility goals were initially determined or modified during follow-up sessions, clinicians could specify the necessary seating components and the suitable type of wheelchair that best fit the particular client. Then a computer search could be performed to check whether all these equipment were available for use. This information system also kept a record of all on-loan equipment, so that clinic staff could maintain a good collection of frequent use item in stock. Further, the system could also provide statistic reports showing monthly/annual summary of clinic attendance. This information was valuable for the planning of future development of the services.

Research Purpose

The developed information system could also facilitate clinical research in the area of seating and mobility. The treatment record of each individual patient provided a comprehensive view on the outcome between each intervention. The visual database provided information on dynamic wheelchair propulsion, ADL activities, change of skeletal deformities and seat pressure distributions. These information were valuable for conducting longitudinal studies to reveal the effectiveness of providing seating and mobility intervention. In addition, the loan records of the wheelchair bank could also provide data, which revealed the specific needs of the types and configuration of wheelchairs, as well as seating components that were particular useful for patients with a specific type of neuromuscular diseases.

## DISCUSSION

Development of medical informatics is becoming the major trend in world wide clinical areas. Computerized database has the extensibility to further link up databases from different clinics within the hospital. Through such arrangement, clinicians will be able to access a complete medical history of the patient via a computer terminal situated in any clinic room. The accessibility of the database can be also extended to clinicians of other hospitals, provided that proper security measures were incorporated. Through information networking, patients can enjoy a more efficient treatment in hospitals. However, there are still limitations to the current system. In terms of data storage, the use of CD-ROM is just an intermediate solution for handling the massive video information for each patient. The use of a video server or other storage media should be considered to enhance the data retrieval speed. For data entry, particular during assessment, voice input should be considered. In this way, therapist can input measured data directly into the database while their hands are still free to provide support to the patient's body. In addition, they can also use verbal commands to capture any important visual images, including body deformities, contractures and wounds during the assessment. This can help to improve the operation of the clinic.

In the future, this information system will be extended to allow access via the Internet. Web based information system has the advantage of quick access and updating. This could facilitate international exchange of expertise in the specialized area of seating and mobility. Also, web base information system can also support domiciliary therapeutic services, where clinicians from various hospital and rehabilitation centres can offer seating service via telecommunication systems.

## CONCLUSION

Computerized database could be used to provide fast retrieval of patient records during seating clinic operation. Access to a complete medical history of these patients is essential to clinicians in planning for suitable interventions. This integrated information system can also contribute to professional educational in this specialized area of seating and mobility, as well as providing support for conducting related outcome researches.

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# A3 MODEL DIAGRAM DEVELOPED AS ACCESSIBILITY AND UNIVERSAL DESIGN INSTRUCTIONAL TOOL

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## ABSTRACT

Project IMPACT's (Integrated Multi-Perspective Access to Campus Technology) A3 Model, previously referred to as the AAA Model, was developed to clarify different methods or approaches used by organizations to create accessibility for people with disabilities. A diagram, titled "A3 Model and Transition of Approach," has been developed to illustrate the A3 Model. It is used in instruction related to accessibility and universal design (UD). This paper describes the diagram, including the development, instructional techniques, and its relationship to assistive technology and universal design.

## BACKGROUND

The AAA Model was developed as a result of Accessibility Audit projects, which revealed that some students were interpreting the term 'accessibility' in different ways (1). The model's name was later changed to the A3 (Advocacy, Accommodation, and Accessibility) Model. Further observation of this phenomenon indicated the presence of three developmental phases related to accessibility (2). Connel, et tal., describes universal design as, "The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design" (3). Project IMPACT uses the term 'accessibility' in the context of universal design and in a broad sense to refer to a state where products, environments, services, etc. can be used by people with cognitive, motor, and sensory disabilities without alternate or additional locations, costs, services, or devices. The development of this diagram supports the need for audiences in disability related instruction to be able to understand accessibility in terms of universal design, rather than individual accommodation.

## OBJECTIVE

The objective of this work is to develop an instructional tool to illustrate the developmental phases of the A3 Model. It is vital that this tool present information in a way that could be understood by audiences with various disability and accessibility experience.

## METHODS

Early diagrams of the A3 Model consisted of a line with advocacy, accommodation, and accessibility labels displayed from left to right on the line to indicate a continuum between these three approaches. Therefore, an organization's approach to meeting the needs of people with disabilities could be between two phases, indicating a blend of approaches. However, this diagram did not effectively highlight the presence of the other components in each phase.

The diagram was later expanded (Figure 1) to illustrate how advocacy, accommodation, and accessibility contributed to each phase and how each changes throughout the phases. Theoretical relationships of advocacy, accommodation, and accessibility are demonstrated as a function of time in a 100% stacked area chart.

The diagram indicates that during the Advocacy Phase an organization minimally anticipates the needs of people disabilities and is reactive to complaints. Accessibility and accommodation exist in small proportions and increase throughout the phase. An organization may begin moving towards the Accommodation Phase as it begins to anticipate needs.

The organization enters the Accommodation Phase when its primary method of meeting the needs of people with disabilities involves anticipating needs and establishing accommodation systems. As the ability to accommodate increases, the need for advocacy continues to fall. During this phase, the organization may more actively explore accessibility.

An organization may choose to shift its focus towards accessibility as it discovers that better design can reduce the need for individual accommodation. In the Accessibility Phase, accommodation and advocacy are still believed to be present, as true accessibility is viewed as an unattainable goal due to the dynamic nature of environments and the wide range of severity of disabilities. The arrow at the bottom of the chart, pointing from left to right, indicates that the transition towards the Accessibility Phase is preferred in the developmental process.

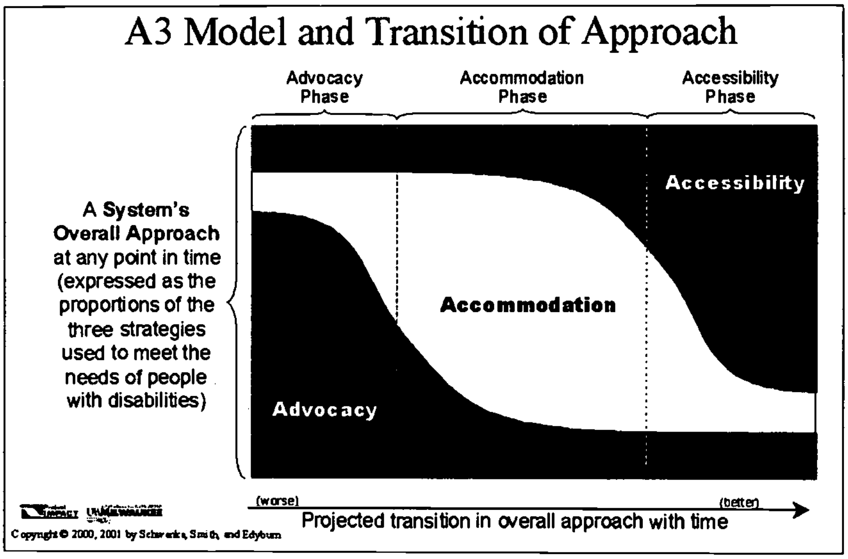


**Figure 1: A3 Model and Transition of Approach Diagram**

Assistive technology is included as a component of the Accommodation Phase and universal design is included in the Accessibility Phase. Therefore, this diagram and model promotes improved design, which may reduce the need for assistive technology.

Questions during presentations indicated that some audiences were having difficulties understanding the diagram due to its complexity. Therefore, after providing an overview of the diagram, the phases were visually isolated (Figures 2-4) using multimedia animation techniques or using sheets of paper to cover portions of a traditional overhead transparency of the diagram.

## RESULTS AND DISCUSSION

The diagram has been used in a variety of presentation settings with audiences who have a range of disability related knowledge and experience. Settings have included: professional conferences, undergraduate occupational therapy courses, graduate occupational therapy courses, accessibility related trainings, and enrichment courses. Its use has been well received and often stimulates related questions. Audience members and students have demonstrated understanding of the diagram through categorization exercises.

The isolation of the phases (Figures 2-4) has been an important technique to aid initial understanding of the diagram. This allows the instructor to focus the audience's attention, emphasize the primary components in each phase, and link examples to the explanation.


**Figure 2: Advocacy Phase of the A3 Model Diagram**


**Figure 3: Accommodation Phase of the A3 Model Diagram**

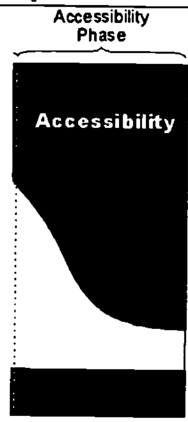


**Figure 4: Accessibility Phase of the A3 Model Diagram**

It is important to note that A3 Model Diagram primarily represents effort committed to the various approaches rather than outcomes or effectiveness. However, it does indicate that movement toward accessibility theoretically could reduce the need for advocacy and accommodation.

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# THE OHIO ASSISTIVE TECHNOLOGY DISTANCE LEARNING PROJECT: EVOLUTION TO WEB-BASED EDUCATION AND THE IMPLEMENTATION OF AN IMPACT STUDY.

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## ABSTRACT

The Ohio Assistive Technology Distance Learning Project (OATDLP) has provided distance learning opportunities since 1997. Initially, the OATDLP offered 14 courses on various AT topics based on course learning kits developed by the University of New Mexico's RIATT project, utilizing Ohio-based faculty who communicated with project participants via the use of dedicated listservs. Now in its fourth year, the OATDLP offers 19 courses, the majority of which are web-based. OATDLP participants who have completed 5 or more courses are eligible and invited to apply to the Impact Study, a phase of the project that evaluates the effects of the OATDLP training on the educational placement and performance of students with disabilities.

## BACKGROUND

The OATDLP was proposed in March 1997, and initiated in October 1997, to provide distance learning opportunities to school-based personnel in Ohio. The Ohio SchoolNet Commission, an office created by the Ohio legislature to meet the technology needs of Ohio schools funds the distance learning project. Additional partners include the Northwest Ohio Educational Technology Foundation (NWOET), Bowling Green State University (BGSU), and the Ohio Special Educational Regional Resource Centers (SERRCs).

As of January 2001, the OATDLP offers 19 courses with three additional courses in development. Six to eight courses are scheduled during five sessions each academic year, between September and July. Each course term is six weeks, and participants receive one graduate credit hour upon completion.

## TRANSITION TO WEB-BASED INSTRUCTION

In 1997, all 14 courses used dedicated listservs for participant and faculty exchange, and students received their course materials in learning kits delivered by standard mail services. Currently, the use of dedicated listservs for class discussion is reserved for two introductory courses. The majority of the courses are now web-based, using the WebCT environment, and message boards are incorporated into the course websites for participant and faculty interaction. The course materials and syllabi have evolved to include current readings, reference materials, and assignment, most of which are made available via the web in an effort to facilitate participant access and to minimize the distribution needs on the project staff.

## IMPACT STUDY

The OATDLP has developed a mechanism for project evaluation that provides assistive technology to students as a way of validating its effectiveness in preparing educators to make appropriate assistive technology decisions for their students. Through the Impact Study, all participants who have taken five or more OATDLP courses are eligible to submit proposals for assistive technology for a student (or students) with whom they are working. Goals for the research study are to establish that, as a result of the education team's participation in the OATDLP, students with disabilities receive:

-Quality assistive technology assessments;

-Appropriate assistive technology devices and services based on assessment and according to an Individualized Education Plan (IEP);

-Training and support from parents and educators with expertise in assistive technology; and

-Opportunities to use the acquired assistive technology to reach higher levels of achievement in the least restrictive environment appropriate for that student.

The study does not supercede the school district's responsibility to provide assistive technology devices and services for identified children. Implicit in the study's application, school districts continue to have the ultimate responsibility for ensuring that children receive the assistive technology they need for a free and appropriate public education.

During the first phase of the Impact Study, 54 applications were reviewed and 23 OATDLP participants received funding for assistive technology for their students. Total funding for the first phase of assistive technology was $118,491.00. The assistive technology was ordered and delivered in March, April and May 2000. Project staff conducted site visits to interview OATDLP participants, students, their IEP teams, and parents to collect impact data. Although the amount of time for which documentation could be collected was limited (due to the academic calendar), the findings were impressive. Case study data indicated that in many cases, the assistive technology had enabled students' performance to exceed the expectations of their teams, and for several students, the technology allowed them to show skill levels that their disabilities had masked.

In the second phase of the Impact Study, 23 applications were received and 22 proposals were funded, totaling more than $75,581.00. Evaluation of and data collection for the second phase is ongoing.

Through the Impact Study, a collaboration of the Ohio SchoolNet Commission and the Ohio Department of Education Office for Exceptional Children, a total of $194,072.00 has been used to provide assistive technology devices and services for Ohio children and youth. A third phase of the Impact Study was announced in December 2000, with applications due in February 2001.

## SUMMARY

With the end of the 1999-2000 school year, the Ohio Assistive Technology Distance Learning Project completed one round of funding providing assistive technology to students with a wide range of disabilities. Observation, documentation and interview data indicated that:

1. Students benefit when they are provided with assistive technology that is appropriate to their needs.
2. IEP teams can make quality decisions when at least one member of the team has received targeted training focusing on assistive technology and is able to lead the team in a comprehensive process that:

   -Includes all stakeholders,

   -Is grounded in appropriate assessment of the needs across environments,

   -Is implemented with a training plan for the student, teachers, aides, and family members to support the use of the technology, and

   -Provides a plan for evaluating the success of the technology

3. Educators from around the state of Ohio are interested in learning about assistive technology when classes/courses are available via distance learning in a web-based format.

Since its debut in 1997 though early fall 2000, the OATDLP has awarded 1336 graduate credit hours, and has had 311 participants. Of the participants, 2 students have completed 15 courses, 7 students have completed 10 courses, 17 students have completed 8 courses and 62 students have completed 5 courses.

**FUTURE PLANS**

The OATDLP continues to plan and develop new course materials and topic areas. The transition to a fully web-based format for all courses is planned, with the acknowledgement that changes are needed to address web accessibility of the courses. Currently, alternate web environments are being researched by project staff and expert consultants to assure accessibility.

For the first time, the 2000-2001 academic year will offer courses for professional development contact hours (PDCHs), as well as for graduate credit. This will make the courses available to participants who do not require or are not eligible for graduate credit, such as family members of students with disabilities, undergraduate students, and therapy assistants.

The OATDLP staff and faculty of the Bowling Green State University are investigating opportunities for graduate degree program status, which would enable participants to apply their OATDLP coursework to the pursuit of a graduate degree specializing in assistive technology. Opportunities to expand partnerships with other universities and to provide course access to participants outside the state of Ohio are also being considered.

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WebCT, *WebCT, Inc.*, Six Kimball Lane, Suite 310, Lynnfield, MA, 01940, www.webct.com.

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# Quantifying Function and Outcomes (Topic 7)

# DO CERTAIN GROUPS OF OLDER PEOPLE BENEFIT THE MOST FROM THE USE OF POWERED WHEELCHAIRS?

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## ABSTRACT

An increasing number of older people want to be active and get about in spite of impairments, a fact causing pressure on public budgets. A study of 111 older people's use of powered wheelchairs has been carried out in order to investigate whether some groups of older people have better outcomes of powered wheelchairs than other groups. The result showed that a vast majority considered the powered wheelchair to be important and that they were satisfied with it as a whole. The characteristics of the users who seemed to get the best outcome were diverse and so were the outcomes for various groups. Since one sort of outcome cannot be regarded as more important than another, no group of older people who benefit the most from powered wheelchairs is identified in this study.

**KEYWORDS:** Elderly people, mobility devices, personal characteristics, outcome evaluation.

## BACKGROUND

The lifestyle of older people is changing these years, and many more wish to be active when they grow old (1). In spite of functional limitations they want to carry out usual daily activities, and in order to do so an increasing number of older people with limited walking abilities wish to use a powered wheelchair. In the Nordic countries assistive technology is granted for free in order to make everyday activities possible, especially in cases when training of functional capacity is not possible or feasible. Lately the municipalities are receiving an increasing number of applications from older people, a group that formerly rarely applied. As powered wheelchairs may be rather costly (about $200-2000 depending on the model and need for adaptation) the pressure on public budgets is increasing (2). There are no objective criteria for assessing the probability of a user's benefit from a powered wheelchair and very little research has been carried out about the benefits of powered wheelchairs (3).

## AIM

The objective of the study was to describe older users' benefit from and satisfaction with powered wheelchairs as a solution to mobility problems, and to analyse these factors in order to determine the characteristics of the users who benefit the most from powered wheelchairs.

### DESIGN, METHOD AND MATERIAL

The study was a cross-sectional structured interview study. The sampling is basically a cluster-sampling where 1/3 derived from large (population >100.000), 1/3 from medium size (10.000-100.000) and 1/3 from small municipalities (<10.000) in Denmark. The municipalities were selected randomly within each cluster, and from each municipality a set number of users was selected at random. The selected users were at least 65 years old and had used a powered wheelchair for at least one year. Staff from the municipality contacted them in order to get consent, and afterwards the interviewers contacted those who agreed to participate. The users were interviewed in April – June 2000 by experienced interviewers. A structured questionnaire was used, comprising questions on background, functional abilities (SIP was used to measure walking abilities), psychological characteristics, use of the powered wheelchair, characteristics of the wheelchair, the service delivery process and environmental factors. Questions on outcome were about goal-attainment, preferences, importance, independence, satisfaction (Danish version of the QUEST v.1 was used), and frequency of use.

Frequencies were computed, and the Chi-2 test was used to calculate the statistical differences between groups. Odds ratios (OR) were calculated with 95% confidence intervals.

## RESULTS

In all, 153 users were contacted, while 120 gave their consent. At the time of the interviews five could not be interviewed, and four turned out not to fulfil the inclusion criteria. Thus, 111 users participated in the study. There was no statistical difference between the participants and the 38 who were not interviewed. The average age of the participants was 77 (66-92) years. 51% were men and 49% women. 48% could only get about in a wheelchair and 80% only used the powered wheelchair outdoors. 25% of the wheelchairs were joystick-controlled and the rest were a scooter model. 65% went out in the wheelchair at least once a day in the summertime and 42% at least once a week in the wintertime. In the summertime the main purpose for going out in the wheelchair was just to take a ride (83%), while 78% went shopping in it. In addition, many used it for visits to friends and relatives.

**Table 1**. Personal characteristics associated with a positive outcome of powered wheelchairs as a solution to mobility problems. $P<0{,}05$. (N=111).

| Personal characteristics | Outcome | Odds ratio |
|---|---|---|
| <77 years old | Better goal-attainment. | 3,0 (1,0-9,0) |
| | More frequent use in the summer | 3,4 (1,5-7,5) |
| | More frequent use in the winter | 2,7 (1,2-5,9) |
| Relative good walking ability (SIP=316-353)* | Preference of the powered wheelchair as means of transportation | 3,0 (1,2-7,2) |
| Rather impaired walking ability (SIP=136-315)* | Willingness to pay partly for the wheelchair themselves | 3,8 (1,4-10,3) |
| | Feel more independence to get about more freely | 13,8 (2,4-78,3) |
| No visual problems | Better goal-attainment | 3,1 (1,1-21,1) |
| | Willingness to pay partly for the wheelchair themselves | 3,6 (1,3-9,8) |
| | More satisfied with the wheelchair's characteristics | 2,9 (1,2-6,5) |
| Can transfer to the wheelchair without help | Better goal-attainment | 8,4 (2,9-24,1) |
| | Feel more independence to get about more freely | 6,5 (1,2-6,5) |
| High degree of self-efficacy | Willingness to pay partly for the wheelchair themselves | 3,5 (1,2-10,1) |
| | More satisfied with the wheelchair as a whole | 4,0 (1,3-12,4) |
| High spirits | Willingness to buy a wheelchair themselves | 3,7 (1,3-11,1) |
| | More satisfied with the wheelchair as a whole | 4,0 (1,2-13,3) |
| | More satisfied with the service delivery | 3,5 (1,2-10,0) |

*SIP is an ordinal scale. In the part about walking ability which has been used in this study 136 corresponds to 'not able to walk at all' and 353 to 'can walk short distances, but with difficulty'.

A number of different outcomes were identified. The vast majority (98%) considered the powered wheelchair to be important and most of them (89%) thought that the wheelchair gave them freedom to get about without support from others. Most of the users were satisfied with their powered wheelchair as a whole (87%) and more than three quarters (76%) could use their powered wheelchair to go to the places they wanted to. The results of the analysis of associations between personal characteristics and outcome show a diverse picture. The personal factors improving the chance of positive outcome are displayed in Table 1.

## DISCUSSION

A powered wheelchair is an important device for older people who have reduced walking abilities. A vast majority thinks that the wheelchair is important and that it gives them freedom to get about without help from others. This matches earlier findings in studies on powered wheelchairs for other age groups (4,5). The users are generally satisfied with their powered wheelchair, but a number of users is not satisfied with some of the technical characteristics of the wheelchair like power and speed, even though it is not as many as seen in other studies (6).

The characteristics of the users who seem to get the best outcome are diverse and so are the outcomes. This corresponds with the notion that using powered mobility is a complex task (3). Users younger than 77 years old have better chances of goal-attainment and of using the powered wheelchair frequently. However, there is no difference in age groups in terms of independence, preference of means of transportation and satisfaction. Since independence may be more important to a user than for instance how often they use the wheelchair, and since nearly all users regard the wheelchair as important, this study gives no clear indication that certain groups of older people benefit more than other groups from powered wheelchairs. In conclusion, outcome differs among various groups and the characteristics of the wheelchair and environmental factors can be expected to play an important role for users' perceived benefits of powered wheelchairs (7).

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# EFFICACY OF SERVICE DOGS AS A VIABLE FORM OF ASSISTIVE TECHNOLOGY

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## ABSTRACT

The population of wheelchair users has almost doubled between 1980 and 1990[1], accelerating both the development and use of assistive technologies to increase independence for wheelchair users. Service dogs have been used as a viable solution for many wheelchair users. In addition to reports of improved level of independence and increased psychological well-being, service dogs are reported to reduce the expenditure of time and physical exertion by the owner, allowing individuals more efficient use of limited energy. A comprehensive questionnaire was administered to investigate differences in psychosocial and functional outcomes between wheelchair users who own a service dog (n=20) and wheelchair users who have not yet received a service dog (n=29). Results indicate that service dog ownership is associated with psychosocial benefits.

## BACKGROUND

The United States wheelchair user population is currently estimated at 1.4 million individuals[2]. The needs of this population have accelerated the development of assistive technologies to increase independence and enhance opportunities for wheelchair users. Service dogs have been used as a viable solution for many wheelchair users. Service dogs are trained to retrieve items, pick up things that have dropped, assist with opening and closing doors, help maintain sitting balance, help with mobility issues such as pulling the wheelchair, assist with transfers (body support/bracing) and seek emergency help. They also provide constant companionship. Recent estimates indicate that approximately 10,000 individuals currently use a service dog for mobility related impairments.

In addition to reports of improved functioning, there is a small but growing body of research indicating that people with disabilities who use a service dog report improved psychological well-being, engage in more social interactions and have more friends than people with disabilities who do not utilize a service dog. Scientific literature has shown that psychosocial factors play a significant role in adapting to, and living with, chronic conditions. Conditions such as spinal cord injury, multiple sclerosis, cerebral palsy and muscular dystrophy affect not only physical function and well-being but also significantly impact self-esteem and lead to distressing emotions such as anxiety, depression, resentment, and helplessness. The loss of key roles and disruption of social interactions and future plans are also correlated with chronic conditions and can negatively impact social functioning. We know through numerous studies that an individual's social network and social support system are related to psychological well-being and healthy functioning. The introduction of a service dog represents an intervention believed to positively affect psychosocial aspects of an individual, leading to increased social integration and social functioning.

Unfortunately, results of the existing research are limited in generalizability due to the retrospective nature of the majority of studies, small sample size, subjective self-report, and in some cases the use of unvalidated measurement tools. This analysis is part of a pilot study designed to both validate existing published results regarding healthcare utilization and psychosocial impact of service dogs, and to expand the research through investigation of social integration and functional outcomes. This paper presents the results of a cross-sectional analysis of psychosocial and functional data collected from existing service dog owners and individuals who have not yet received a service dog.

## RESEARCH QUESTION

Do wheelchair users who own a service dog exhibit better psychosocial and functional outcomes as compared to wheelchair users who are on a waiting list to receive a service dog?

## METHODS

### Subjects

This pilot study has been conducted as a cross-sectional study. All subjects are ≥18 years of age, and use a wheelchair or scooter as their primary means of mobility. The S-DOG group is comprised of individuals who own a service dog. The NO-SDOG group is comprised of individuals who are listed on one of two national service dog agency waiting lists. Subjects were identified and recruited through one of two service dog agencies: PAWs With a Cause®, or Canine Companions for Independence. Selected subject demographic and socioeconomic data is presented in Table 1.

**Table 1: Selected Subject Demographics**

| Variable | S-DOG (n=20) | NO-DOG (n=29) |
|---|---|---|
| Age | 43 (S.D. ± 13) | 41 (S.D. ± 11) |
| % Female | 71% | 72% |
| % Caucasian | 89% | 85% |
| Yrs of Disability | 18 (S.D. ± 17) | 18 (S.D. ± 13) |
| Yrs of Education | 14 (S.D. ± 4) | 15 (S.D. ± 2) |
| Yrs SD Owned | 3 (S.D. ± 2.6) | ---- |
| % Employed | 38% | 45% |

### Instruments

Psychosocial well-being is measured using the following three instruments: 1) Positive and Negative Affect Scale (PANAS) - a 20-item scale assessing both positive and negative affect. Total scores range from 10–50; 2) Rosenberg Self-Esteem (RSE) scale - a 10-item Guttman scale assessing self-esteem, with scores ranging from 10 (low self-esteem) to 40 (high self-esteem); and 3) Social Provisions Scale (SPS) - a 24-item questionnaire assessing categories of perceived social support. SPS scores range from 24 (low social support) to 96 (high social support).

Functional outcomes and community integration are measured using the Craig Handicap Assessment (CHART). Dimensions analyzed for this report are mobility, occupation and social integration. For each dimension, a total continuous score is calculated. A score of 100 equates to no handicap in an individual's ability to perform the particular item/function being measured.

Reliability and validity have been established and published in the literature for all psychosocial and functional questionnaires.

### Data Analysis

All questionnaires were scored according to published guidelines. Statistical analysis was performed using SAS. For continuous variables, a comparison of results between groups was performed using the student t-test. For categorical variables, a comparison of results between groups was performed using chi-square.

## RESULTS

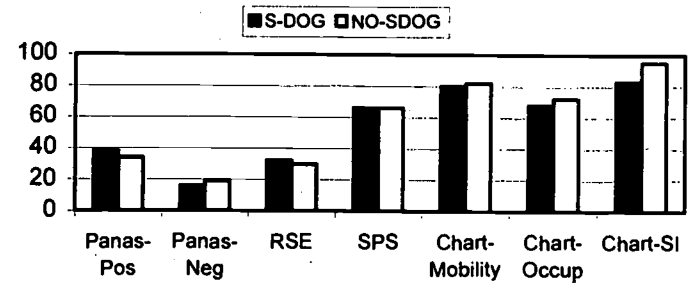
Questionnaires have been received, and data has been analyzed for 20 S-DOG subjects and 29 NO-SDOG subjects. As presented in Table 1, there are no significant differences between the groups with respect to age, gender, race, or years of disability or education. We have observed that S-DOG subjects who are not employed are more likely to self-report their employment status as due to personal choice, as compared to unemployed NO-SDOG subjects, who are more likely to self-report their employment status as due to disability.

Analysis of psychosocial measures indicates that limited differences exist between these groups. On the PANAS, S-DOG participants scored as having greater positive affect (38±5) and less negative affect (16±4) as compared to the NO-SDOG group (means=34±7 and 19±6, respectively).

These differences are statistically significant at $p=0.04$ for both results. With respect to self-esteem, S-DOG participants exhibited modestly higher scores on the RSE (S-DOG mean $=32\pm5$) as compared to the NO-SDOG group (mean$=30\pm6$). No differences were observed regarding categories of social support received by subjects, as measured using the SPS (S-DOG mean $=66\pm4$, NO-SDOG mean$=66\pm5$).

Analysis of functional and community integration indicators using the CHART subscales indicates differences in all three subscales examined. Existing service dog owners self-reported *slightly greater handicap* in terms of mobility and occupational status as compared to non-service dog owners (mobility subscale: S-DOG mean$=81\pm13$, NO-SDOG mean $=82\pm19$. occupation subscale: S-DOG mean$=68\pm27$, NO-SDOG mean$=72+31$). With regard to social integration, S-DOG subjects also reported *greater handicap* (S-DOG mean$=83\pm23$) as compared to non-service dog owners (NO-SDOG mean$=95\pm9$). Differences in social integration scores are significant at $p<0.02$. Psychosocial and functional results are summarized in Figure 1.

Figure 1. Summary Results




## DISCUSSION

Results of this study indicate that the presence of a service dog improves the extent to which a wheelchair user feels enthusiastic and alert (positive affect), and mediates the extent to which a wheelchair user experiences subjective distress such as anger, guilt and fear (negative affect). A modest improvement in self-esteem is observed, but is not statistically significant. No difference is noted in the degree to which an individual perceives social support as a result of owning a service dog. Interestingly, pilot results for functional and social integration outcomes do not indicate that service dog owners perceive less handicap in these areas as compared to non-service dog owners.

Limitations of this study are sample size and cross-sectional design. Scientific evidence of changes in psychosocial and functional outcomes over time as a result of service dog ownership remains limited. It is possible that scores from existing service dog owners participating in this study represent significant improvements as compared to their pre-service dog ownership status. Future studies should follow service dog recipients over time to determine long-term psychosocial and functional benefits within this group.

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# UNOBTRUSIVE VITAL SIGNS MONITORING FROM A MULTISENSOR BED SHEET

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## ABSTRACT

Chronic sleep disorders affect more than 50 million people in the U.S., and there are numerous clinical populations, such as spinal cord injury patients, cognitively-impaired elderly persons living at home, and infants at risk for Sudden Infant Death Syndrome, who could benefit from unobtrusive, long-term monitoring. The prototype SleepSmart sheet is a thin, full-length, multi-sensor mattress pad. It is controlled by software to detect heart rate, breathing rate, body orientation, and index of restlessness. A spectral analysis module is combined with an event detection module to accumulate nightly reports and signal alarms when appropriate. Lab bench testing has confirmed the effectiveness of the sensors and software algorithms; clinical testing is expected to confirm the ability of the SleepSmart sheet to detect vital signs to within ±10% of conventional, wired clinical devices.

## BACKGROUND

There are many methods of monitoring sleep by putting sensors on the sleeper's body. Polysomography [1] uses wired sensors to measure vital signs (breathing and heart rate, blood pressure), chest wall expansion, airway pressure changes and exhaled air $CO_2$ content, electro-encephalogram (EEG) and body orientation. While this provides a rich data set for the diagnosis of severe sleep disorders such as obstructive sleep apnea, it is expensive, can only be done in the unfamiliar environment of a clinic over one or two nights. A second mechanism to collect sleep data is surveying people who have sleep disorders or their guardians/parents. While the easiest methodologically, this is the least powerful. Actigraphy [2,3] unobtrusively measures gross body movement with a wrist-watch-type data logger that can be worn for weeks. An increase of restlessness has been shown in some cases to correlate to a decrease in sleep quality. In a similar manner, an experimental ring that performs blood oximetry and measures heart rate optically has been developed to send data to a bed-side receiver via telemetry [4]. Another experimental device is the SmartShirt [5,6], an undergarment with woven-in wires and snaps to connect to sensors and a wearable computer for telemetry to a base station. The sensors can measure vital signs such as breathing and heart rate.

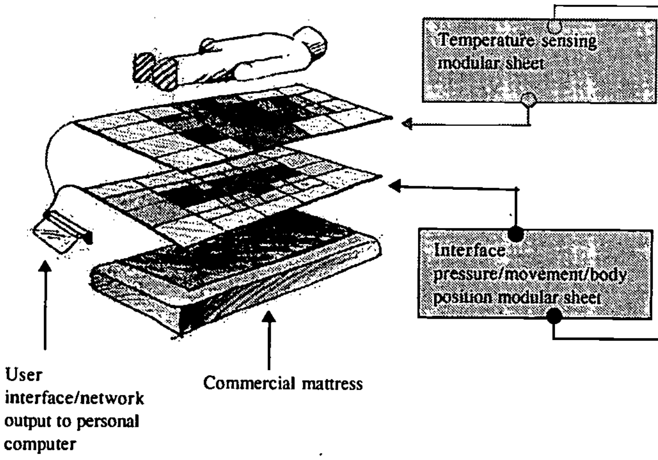
While these sensor systems are person-based, another class of sensors are bed-based. Many devices have been developed and patented for body position, breathing rate, and heart rate [e.g., 7] using force sensitive resistors, capacitive sensors, piezo-electric sensors, and microphones. However, they can be expensive and may require wired electrodes for many of the sensing functions [e.g., 8,9].

## RESEARCH QUESTION

The goal of the SleepSmart Project was to develop a low-cost, multi-sensor, modular, unobtrusive bed sheet that was breathable, impervious to liquids and washable. The frequency-based software algorithms requirements included heart and breathing rate, body position and motion, and surface temperature (also used as a redundant sensor for body presence). The event-based diagnostic module would reduce and store data to allow 24-hour reporting as well as recognizing and alerting the medical staff in the case of clinically-derived alarm conditions.

## APPROACH

The SleepSmart system (patent application filed September, 2000; see figures 1 and 2) uses an array of 54 force sensitive resistors (FSRs) and 54 resistive temperature devices (RTDs). The array is denser (10 cm spacing) under the torso than the legs (20 cm spacing). All of the sensors have 10-Hz cutoff low-pass filters. Twelve of the torso FSRs have an parallel high-gain AC-coupled signal conditioning circuit to facilitate heart rate detection. All 120 channels are recorded at a 100 Hz scan rate. Digital wavelet transformation software measures average heart rate at a resolution of 0.5 beats per minute using 5-second data sets. Breathing rate is measured every 5 seconds using 25-second data sets. Body center of mass is measured using moment calculations of the low-pass-filtered FSR and RTD signals. A restlessness index is calculated by integrating the absolute change in body center of mass over the duration of sleep at 25-second intervals.



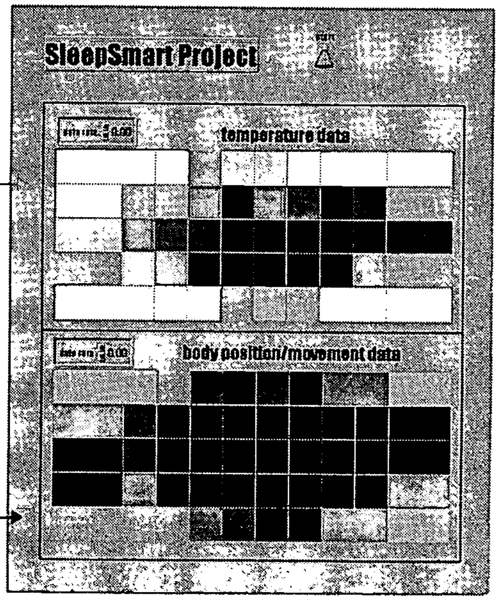




**Figure 1; prototype concept demonstrating layered sensor approach; each layer can be updated /removed depending upon the users' needs or new technological innovations**

**Figure 2; graphical user interface concept for clinical studies; pressure/temperature information is displayed chromatically and recorded for analysis**

## RESULTS

Bench testing has shown that heart rate can be measured reliably if an FSR sensor is within 2cm of the projected location of the heart on the mattress and is not significantly affected by body orientation. The wavelet transformation software computes the heart rate at the 12 torso sensor locations and selects the sensor with the strongest amplitude. Breathing rate software uses a similar algorithm, but the chest wall movement is readily measured at a number of the sensors due to its gross nature.

## DISCUSSION

While bench testing of the hardware configuration and the major software modules has been completed, the current effort of the project is devoted to system integration and clinical testing at the VA Palo Alto Sleep Disorder Clinic. Clinical tests (March, 2001) are expected to show that wired, state-of-the-art, breathing and heart rate detection devices have a higher resolution than SleepSmart. However, this is not critical due to the function of each of the devices. SleepSmart is expected to have an equal or better performance in the event of the sleeper rolling over, which may cause electrode detachment with a wired sensor or a temporary loss of signal for SleepSmart.

Further work in this area will focus on developing advanced software to correlate SleepSmarrt sleep profiles with the results of polysomnography data, and the incorporation of fabric-based sensing technologies to further reduce costs of the SleepSmart system.

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# COMPARISON OF PUSHRIM KINETICS BETWEEN FOUR DIFFERENT MANUAL WHEELCHAIR PUSHRIM CONDITIONS

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## ABSTRACT

High repetitive forces to the pushrim have been hypothesized to cause various upper extremity injuries in manual wheelchair users (MWU). The aim of this study was to determine the kinetic changes occurring at the pushrim in relation to four different wheelchair pushrim conditions. A sample of 48-experienced MWU was investigated using a 3-D SMART$^{Wheel}$ system to analyze four different pushrim arrangements (anodized with and without the use of gloves and vinyl coated pushrims with and without a paxbac) at 0.9 and 1.8 m/s. The results revealed that the use of gloves displayed a significantly ($p<0.05$) lower radial force compared to two of the other three conditions. Also, a trend of decreased resultant force was observed when gloves were used. Insight into the kinetic differences a MWU encounters when utilizing various wheelchair arrangements may assist researchers in their quest of finding the ideal wheelchair setup.

## INTRODUCTION

Manual wheelchair users (MWU) have shown to have a high prevalence of carpal tunnel syndrome (4). Increased pressure and or repetitive trauma to the carpal tunnel from large forces and moments not used for propulsion have been thought to be the cause of this injury (4). In the past, researchers have hypothesized that varying the wheelchair pushrim setup may reduce potential damaging forces and moments applied to the wrist during propulsion. Shimada et al. examined seven-experienced (6 male, 1 female) MWU and studied the forces and moments that were applied to the pushrim during propulsion. The subjects performed ten strokes on anodized pushrims with and without the use of fingerless gloves at 1.8 m/s. They found that the use of gloves significantly ($p<0.05$) increased the motive force and moment to propel a wheelchair. The author's concluded that the use of gloves provides enhanced coupling of the hand to the pushrim decreasing the need for frictional forces not used for forward motion. Koontz et al. studied the forces and moments of 12 experienced (6 females, 6 males) MWU propelling their own wheelchair at two speeds (1.3 and 2.2 m/s) for 20 seconds. Anodized and vinyl-coated pushrims were tested and compared. The author's found that the resultant force had significantly ($p<0.05$) decreased when the MWU propelled with the vinyl-coated pushrims. Koontz et al. suggest that the reduction of overall forces applied to the pushrim may help to reduce the risk for upper extremity injury to occur. The purpose of this study is to expand on the current base of knowledge and examine the biomechanical changes that occur in MWU when propelling with four dissimilar pushrim arrangements.

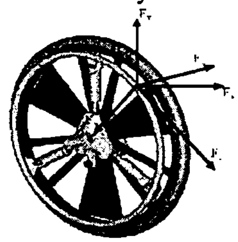
## METHODS

*Subjects*. Forty-eight experienced manual wheelchair users (37 male and 11 female) with spinal cord injuries of T4 level or below ($11.72 \pm 6.74$ years post operation) volunteered for the study. The mean age, height and weight of the subjects was $39.17 \pm 11.71$ years, $176.29 \pm 8.68$ cm and $754.26 \pm 188.78$ N weight. Informed consent was obtained prior to data collection.

*Kinetic Data Collection*. The kinetic data was collected at 240 Hz for 20 seconds by a force and torque sensing pushrim (SMART$^{wheel}$) that is able to measure three-dimensional forces (Fx, Fy, Fz)

and moments (Mx, My, Mz). These forces were placed into a local coordinate system consisting of resultant force (F), radial force (Fr) and tangential force (Ft) illustrated in figure 1 (1).
*Experimental protocol.* Each subject's individual manual wheelchair was fitted with a SMART$^{Wheel}$ on both sides and secured onto a dynamometer (5). The subject's performed the testing protocol with one of the four conditions in a randomly selected order. The wheelchair conditions consisted of: anodized pushrims, anodized pushrims with the MWU wearing gloves, vinyl coated pushrims and vinyl coated pushrims with a supporting paxbac placed onto the back of the wheelchair. Five consecutive propulsion trials were analyzed at two steady state speeds of 0.9 m/s and 1.8 m/s.
*Statistical analysis.* A Univariate ANOVA with dependant variables of velocity (Vel), rate of rise of the resultant force (Rr), applied forces (F, Ft, Fr), stroke frequency (Sf), push angle (Pa), and non-planar moment rate of rise and peak (Mprr, Mpp) and an independent variable of conditions (anodized, vinyl, vinyl/paxbac, and gloves). A Tukey post hoc analysis was performed on significant results with the alpha level set at ($p<0.05$).

Figure 1. The global and pushrim coordinate system denoted on the SMART$^{Wheel}$.



## RESULTS

The mean peak values for the right and the left sides and speeds were highly correlated ($r>0.7$). Therefore, the mean variable for each condition for the right and left side and speeds were combined and calculated. The radial force was found to be significantly ($p<0.05$) lower with the use of gloves when compared to the vinyl and the anodized without gloves trials. Table 1 denotes the kinetic variables velocity, weight normalized mean peak forces (Rr, F, Ft, Fr), (SF), (Pa) and (Mpp, Mprr) investigated for 0.09 and 1.8 m/s.

Table 1. The pushrim conditions in relation to the weight normalized mean peak values over five strokes and averaged ± standard deviation velocity (Vel), applied forces (Rr, F, Ft, Fr), stroke frequency (SF), and Non-planar peak and rate of rise moments (Mpp, Mprr). A, B, C, and D denotes which pushrim conditions are significant in relation to one another. * = ($p<0.05$).

| Condition | Anodized (N=25) A | Vinyl (N=11) B | Vinyl/pax (N=7) C | Gloves (N=5) D |
|---|---|---|---|---|
| Vel (m/s) | 1.288± 0.104 | 1.303± 0.095 | 1.336± 0.067 | 1.296± 0.079 |
| Rr (s) | 2.267± 1.006 | 2.610± 0.839 | 2.346± 0.881 | 2.425± 0.637 |
| F | 0.120± 0.031 | 0.121± 0.024 | 0.114± 0.022 | 0.108± 0.023 |
| Ft | 0.090± 0.022 | 0.088± 0.020 | 0.077± 0.017 | 0.069± 0.008 |
| Fr | 0.055± 0.016 D* | 0.056± 0.016 D* | 0.041± 0.014 | 0.035± 0.006 AB* |
| Sf (Hz) | 1.146± 0.194 | 1.158± 0.227 | 1.144± 0.271 | 1.354± 0.167 |
| Pa (θ) | 104.548± 15.048 | 107.969± 16.067 | 104.439± 16.807 | 94.521± 11.464 |
| Mpp (m) | 0.014± 0.010 | 0.016± 0.010 | 0.022± 0.003 | 0.023± 0.005 |
| Mprr (m/s) | 0.236± 0.182 | 0.279± 0.178 | 0.318± 0.197 | 0.367± 0.075 |

## DISCUSSION

The goal of this study was to investigate four different wheelchair pushrim conditions in hopes of finding the most efficient and least potentially harmful setup. Shimada et al. investigated the MWU kinetics when propelling on an anodized pushrim with and without the use of gloves. They found that the MWU produced larger tangential forces with a tendency of less radial force when propelling a wheelchair with gloves. Our finding revealed that the utilization of gloves created significantly less radial force when compared to two of the remaining three conditions. Koontz et al. discovered that vinyl coated pushrims displayed significantly lower resultant forces when compared to anodized pushrims. Although not significant, we found that the resultant force tended to be the lowest with the use of gloves when comparing all four conditions. The differences found between studies may be attributed to study design and the number of subjects utilized. The small subject base used in Shimada et al. and Koontz et al's studies performed both of the testing conditions creating a repeated measure and increasing the chance of finding a difference. Our study did not use a repeated measures design – each subject was only investigated for a single wheelchair setup. This makes detecting a difference more difficult, but also increases the chance that the differences seen are real. In this study, the use of gloves presented some biomechanical advantages, but inconclusive results hinder our decision as to which is the most appropriate wheelchair condition. Biomechanical examination of MWU provides insight into the possible mechanisms or solutions needed to combat commonly acquired upper extremity injuries. Further research in this area needs to be done in hopes that the information gained offers an enhanced quality of life for people with disabilities.

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# QUANTITATIVE BALANCE ANALYSIS: ACCELEROMETRIC LATERAL SWAY COMPARED TO AGE AND MOBILITY STATUS IN 60-90 YEAR-OLDS

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## ABSTRACT

This paper examines relationships between lateral sway measured accelerometrically during normal and stressful standing tasks and long-term factors – specifically, age and exercise or mobility status – known to affect balance. Results confirm that low-stress standing is not significantly linked to age and exercise, but that stressful postures (e.g.: toe-to-heel and single-leg stance) are associated with higher sway, increased gender differences, positive correlation with age and negative correlation with self-reported mobility.

## BACKGROUND

The sense of balance declines with age, causing impaired mobility and increased risk of falls. We are developing a clinically-useful instrument for quantifying hitherto qualitative measures of balance in non-laboratory settings, for feedback during therapy and home care, and for preventing falls (1, 2). The computerized wearable accelerometric motion analysis system ("WAMAS") consists of two 3-axis ±5 g sensors attached to both corners of eyeglass frames to measure head motion, and two sensors at each hip on a belt around the waist, along with a self-contained data acquisition package. A remote control is used to command the unit, so the wearer is unencumbered by cables.

Recent progress in sensor technology and portable instrumentation has led to a resurgence in research on balance assessment. Aminian, et al., (3) used a wearable recorder for accelerometry during unconstrained walking. Kamen, et al , (4) used a 3-axis accelerometer over the spine in experiments on standing balance. Manson, et al., (5) described a portable accelerometric system for measurement of tremors. "Activity" monitors employ accelerometers to estimate metabolic rate (6); these are limited by over- or under-counting of contributions of various activities to energy expenditure. We contend that measurement at several body locations yields more information on segment motion [see Figure 1 at right].

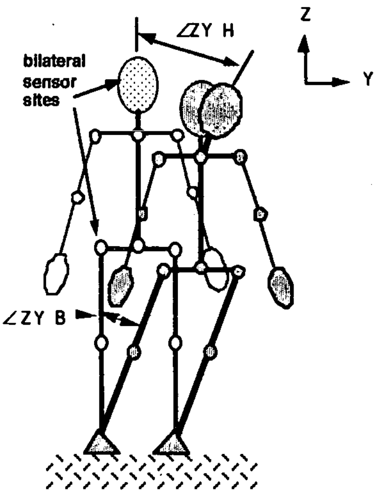



**Figure 1: Lateral sway model**

## RESEARCH QUESTION

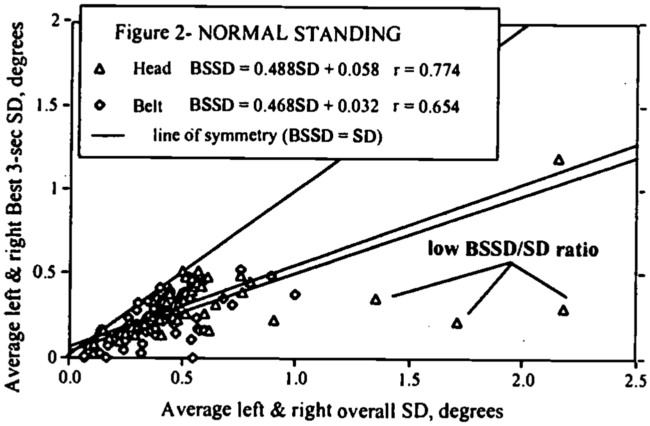
To establish statistical reliability and validity by comparison of accelerometry with laboratory gait and balance measures, male and female subjects aged 60 to 90 years having well-defined mobility status performed a series of standardized balance and mobility assessment tasks using a test-retest protocol. Lateral sway, a common measure of standing postural stability, measured at head and waist was hypothesized to increase in tasks with decreased base of support (e.g.: standing on toes, tandem stance). Similarly, eliminating the visual reference by closing the eyes was expected to increase lateral and antero-posterior sway.

## METHODS

A total of 88 subjects have been tested at least twice. Demographics of the 55 female subjects were: age 75.2 ±5.7 years (mean ±standard deviation), weight 64.5 ±10.5 Kg, height 158.2 ±6.1 cm; males were 73.4 ±6.7 years, 81.0 ±11.9 Kg, 173.0 ±7.1 cm. Mobility was reported for 3 weeks before testing using the "Personal Activity Record" (PAR). Post-test analysis was performed by deriving "angle" $\angle ZY$ = **arc tan (Y/Z)** at each sensor site. For small angles ($\angle ZY<10°$) the gravitational contribution is small (<10%) but nonetheless precludes integration of angular acceleration to obtain exact tilt angle. Standard deviation, $\sigma ZY$, of $\angle ZY$ is a measure of root-mean-square lateral sway over the duration of the whole task ("SD") or a selected interval (usually the 3 seconds during which SD at all four sensor sites is minimum, termed "BSSD"). Linkage of age and exercise to sway was evaluated by Pearson product moment correlation coefficient.

## RESULTS and DISCUSSION

Undisturbed standing represents the least stressful of a spectrum of increasingly difficult postural tasks. One indicator of performance is the ratio of lateral sway during the best ("BSSD") 3 seconds to overall sway ("SD") during a 10-second task. Correlation coefficients were high for lateral sway at both the head (r=0.77) and waist (r=0.65) in normal stance; waist BSSD was < 0.5° and SD<1.0° for all subjects [Figure 2, below]. Sway was much higher in stressful single-leg stance:

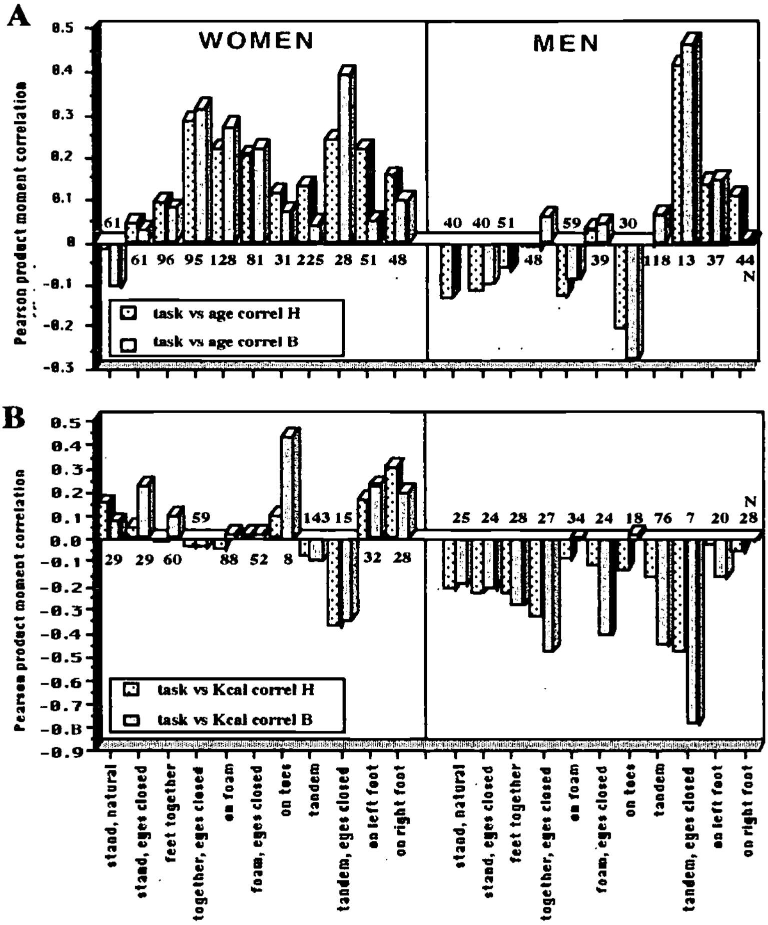



BSSD at the waist ranged up to 4.5° and SD to 10°, with higher scatter away from the symmetry line. The nearer the BSSD/SD ratio is to 1 (the "symmetry line"), the more consistent is the subject's performance throughout the task. A low (<0.33) ratio when the value for SD is high (>1°) is suggestive of loss of balance (see 3 examples in Figure 2).

Low stress standing is characterized by lateral sway near the lower limit that the WAMAS can resolve (±0.005**g**, or $\angle ZY$=0.28°) as well as the lower limit of human postural control; hence, random noise constitutes a large fraction of the sway values being compared. The high sway values of more stressful tasks allow greater individual variation, and thus if conistent, higher test-retest correlation. This was the case with the stand-on-toes task, in which the minimum mean group sway (waist BSSD = 2.14 ±1.49 women, 1.47 ±1.13 men) was the same as the maximum in the eyes-closed standing task (head SD). As expected because of the difficulty of the task, the individual overall SDs were 2.5 to 6 times larger than the BSSDs.

We found no significant relationship between age and instability during natural unstressed stance of normal subjects with or without visual input, similar to other recent reports (7). Women had higher sway with increasing age for all other tasks, although men did not [Figure 3-A]. Higher sway during tandem stance with eyes closed is correlated with increasing age for both men and women [Figure 3-A]; lower correlation with age of waist compared to head sway is indicative of an adequate vestibular function Single-leg stance illustrates effect of dominant limb (lower sway but reduced lower limb motor standing on right leg); others have shown age dependence in effectiveness in this task. stressful tasks like single-leg stance (8)

Self-reported activity level revealed inverse correlation of exercise with lateral sway during tandem stance both eyes-open and eyes-closed [Figure 3-B]; higher mobility was consistently correlated with lower sway in men, but not women. Tandem stance eyes-closed yielded sway consistently negatively correlated with mobility [Figure 3-B]; that is, exercise improves one's ability to perform this task, while increasing age degrades performance.

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# ANALYSIS AND SIMULATION OF UPPER BODY MOTION OF PEOPLE AFFECTED BY LOW BACK PAIN OR SPINAL CORD INJURY

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ABSTRACT

An understanding of differences in movement patterns of people with back pain disability or spinal cord injuries and able-bodied persons may lead to more appropriate ergonomic workplace adaptation. The aim of the proposed work is to characterize and model functional limitations of these three groups of persons in reach and grip tasks. The participants performed reach and grip movements to spatially distributed targets in the frontal, lateral and overhead planes while seated. Empirical data (movement kinematics, 3D trajectories, subjective perception of effort, and EMGs) and modeling (statistical and optimization-based differential inverse kinematics models), are used to determine some limits of functional reach capability and movement strategies.

## BACKGROUND

Back pain problems appear to be the most numerous of occupational injuries, perhaps 4.6 million/year. Spinal cord injuries (~10,000/year) impose severe permanent physical limitations. Persons with spinal cord injuries perform essentially all of their work from a seated position. It is likely that these people use different movement strategies and have different capabilities in seated work, compared to able-bodied persons (1). Looking at proximal muscles only, Seelen (2,3) showed that there is a substantial learning curve for seated balance after a new spinal cord injury. Persons with lower spinal cord injuries appeared to use more complex strategies to react to a pertubation.

Reaching strategies are likely quite different than able-bodied persons, as well. Potten et al. (4) performed an EMG study of forward reach in persons with spinal cord injuries. They demonstrated that traditionally non-postural muscles such as the latissimus dorsi and the trapezius are used to maintain posture. Since these muscles are also used to position the scapula, it is reasonable to believe that the interaction of balancing and reaching results in altered scapular reaching mechanics in persons with spinal cord injuries. An understanding of the relationship between posture and reach is likely to lead to practical interventions. Allison (5), for instance, showed that a spinal orthosis improved the ability of persons with tetraplegia to reach when in the long sitting position commonly used for dressing and bathing.

## OBJECTIVES

The short term objectives of this study is to characterize and model functional limitations of persons affected by low back pain or spinal cord injury, and to determine EMG patterns associated with motion strategies in reach tasks. The general hypothesis is that back problems (pain or spinal cord injury) will contribute to a reorganization of posture and movement strategies.

The long term objectives are to characterize motion patterns associated with back problems, develop motion training programs for patients and use the above information to improve workplace design and rehabilitation procedures.

## METHOD

Loaded reach movements to spatially distributed targets [4 elevations, 3 azimuths (0, 45 and 90°) and 2 distances (close and far)] are performed by each group of subjects (control, back pain and spinal cord injured; 10 subjects/group) starting from an initial seated posture (Figure 1). The seat was designed to simulate a wheelchair. Movement kinematics, 3D trajectories, EMGs, subjective perception of effort, and modeling (statistical and optimization-based differential inverse kinematics models), are used to determine the limits of functional reach-grip-move capability, movement strategies and eventually associate strategies and performance with specific disorders.

The loads are constituted by a light box (12.5 % shoulder MVC) or a heavy box (25% MVC) manipulated with both hands, and a vertical or horizontal cylinder (25% MVC) manipulated with the right hand.

Twelve reflective markers and 5 electromagnetic sensors are placed on the subject to record body links motion (Figure 1). A 6 link kinematics model (hand, forearm, arm, clavicle, trunk, pelvis) represents the upper body.

EMG electrodes are placed over the right anterior deltoid (AD), right upper trapezius (UT), right lower infra spinatus (IS), right pectoralis major (PM), left and right obliques (Ob), left and right erector spinae (ES). Signals are calibrated from two voluntary maximal contractions of each of these muscles.

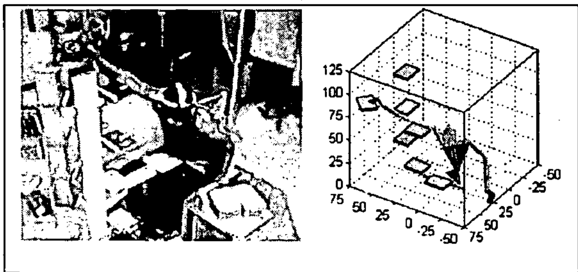

Figure 1. Experimental setup (left) and representation of motion capture (right).

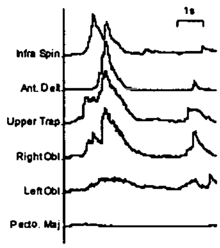


Figure 2. EMG recordings. From top: IS, AD, UT, ROb, LOb, PM (no ES for this SCI subject).

## RESULTS

Preliminary observations indicate that back pain patients refused to reach targets requiring 90° twisting motions or rated them as extremely strenuous (Figure 3). When compared to control subjects, spinal cord injured subjects presented the following characteristics: a) the free hand is used to stabilize upper body posture during the reach phase (holding the bar located on the left side of the seat); b) because of the absence or limited control of back muscles, some targets could not be reached when manipulating the load with two hands (Figure 3); c) the head is used as a counterweight to maintain balance, which is mostly achieved by anticipatory head displacement in the direction opposite to the hand movement; d) hand and torso movements are quasi-ballistic; e) the target shelf is used as a landing support to avoid forward fall of the body; f) the return to the initial position is performed in the same manner while using the shelf reaction to push the body backward after exerting a downward force on the shelf.

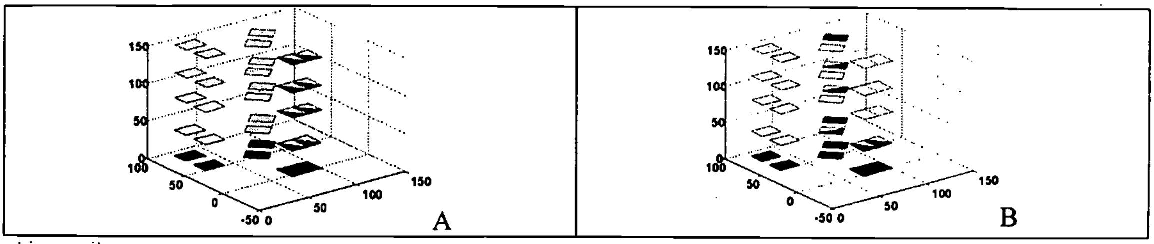


Figure 3. Spatial distribution of targets and target rating. A (low back pain): strenuous (grey), refused to reach (black). B (spinal cord injured) : tried and failed (grey), unreachable (black).

## DISCUSSION

Models describing the motion behavior of each type of participant are investigated; they are dependent on our preliminary observations and dynamic motion data. This study reveals that spinal cord injures subjects use almost uniquely a ballistic mode of movement control, hence relying only on an open loop strategy. This strategy consists in estimating the exact location of the target (early head orientation independent of motion to locate the target) and then trigger a single phase ballistic motion to land the load on target without final feedback correction. Furthermore, anticipatory head and torso movements (mostly rearward) are used to compensate the forward motion of the arm and maintain balance. This feedforward control of the center of gravity, as well as ballistic aiming motions are develop to compensate for the lack of back muscles control.

It is anticipated that the methods developed here can be used as clinical and ergonomic tools to: a) assess limitations, b) identify movement deficits, c) assess recovery and develop adequate training, d) predict movement limitations, e) estimate muscle overload and joint instability, f) determine accommodation needs (workplace, work practice, wheelchair design).

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# EFFECTS OF LOW BACK DISABILITY STATUS ON POSTURAL ENDURANCE TIME DURING STATIC TRUNK POSTURES

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## ABSTRACT

Many work activities require sustained trunk flexion that creates biomechanical loads on the muscles and soft-tissue of the lower back. The resulting strain contributes to fatigue and may lead to acute or chronic low back pain. Workers with chronic low back problems are limited in performing certain job demands and may even lose out on job placement opportunities. A laboratory study was performed to determine the influence of personal (age, gender, and back disability status) and task factors (flexion angle) on the endurance limits for maintaining static trunk postures. Results show a decrease in postural endurance time ranging between 20 and 50 percent for subjects with chronic back pain. Implications of these findings on job design and worker placement are discussed.

## BACKGROUND

Work-related musculoskeletal disorders (WMSDs) affect millions of workers and run up costs exceeding $100 billion in the United States. A common disabling WMSD is chronic low back pain. Chronic back pain has been associated with jobs that require awkward or sustained trunk postures. Despite efforts to improve workplace ergonomics, awkward trunk postures are commonplace. In a survey of automotive workers, (1) found 89 percent of jobs required trunk flexion angles over 20°, and 52 percent of jobs required flexion angles over 45°. Static trunk flexion was observed in 19 percent of the jobs. Several studies have examined the relationship between posture and back pain. In a case-control study of automobile assemblers (2), a strong association (OR 8.1, $p < .05$) was found between back pain and jobs that required non-neutral postures (flexion or twisting angles over 20°). The strength of this association increased with both the duration of exposure and the angular deviation from neutral. In this paper, we present preliminary results from a laboratory study of static trunk flexion postures in a population with chronic low back pain and a healthy control group.

## RESEARCH QUESTIONS

Our study addressed the following questions: 1) Among people with healthy backs and those with chronic back pain, which personal and task factors affect the ability to maintain static trunk flexion postures, 2) What is the nature of this relationship, and 3) How can this information be integrated into clinical evaluation for intervention and accommodation of workers with chronic low back pain?

## METHOD

80 subjects, 40 males (M) and 40 females (F), from two age groups, 20 to 40 years (Y) and over 50 years (O), took part in the study. Of these, 40 were diagnosed with chronic low back pain (P) and the remaining 40 had healthy backs (H). There were 10 subjects in each of the eight age/gender/back status categories; HOF (mean age 59.7 years), HOM (mean age 62 years), HYF (mean age 27.6 years), HYM (mean age 26.5 years), POF (mean age 60.3years), POM (mean age 59.3 years), PYF (mean age 33 years), and PYM (mean age 31.7 years). Participants with healthy backs were currently-employed, working at least 20 hours per week, with no history of back pain,

and no other health conditions to preclude participation. Subjects with chronic low back pain were diagnosed with low back pain lasting at least 3 months, with no history of back surgery, and no other health conditions contraindicating participation. Most of these subjects were on work restriction or currently unemployed due to their back condition.

Prior to testing, subjects completed questionnaires on their work habits and health/fitness history. Anthropometric measurements of height, weight and grip strength were recorded. Five static postures, presented in random order, were tested at 0° (neutral), 15°, 30°, 45° and 60° of trunk flexion. The subject was instructed to hold each posture for as long as possible until he/she reached the maximum pain tolerance limit, or for a maximum duration of 600 seconds, whichever occurred sooner. The measured time was recorded as the Total Endurance Time (TET). During the testing, subjects rated discomfort in their lower back using a Visual Analog Scale (VAS). Surface EMG was also recorded from the erector spinae muscles at the L4-L5 level. At the end of the task, subjects completed a discomfort survey form.

## RESULTS

Figure 1 summarizes results from the 80 subjects. Total Endurance Time (TET) is plotted as a function of trunk flexion angle for each of the eight age/gender/back strata. Persons with healthy backs are shown with solid lines while persons with chronic back pain are shown with dotted lines.

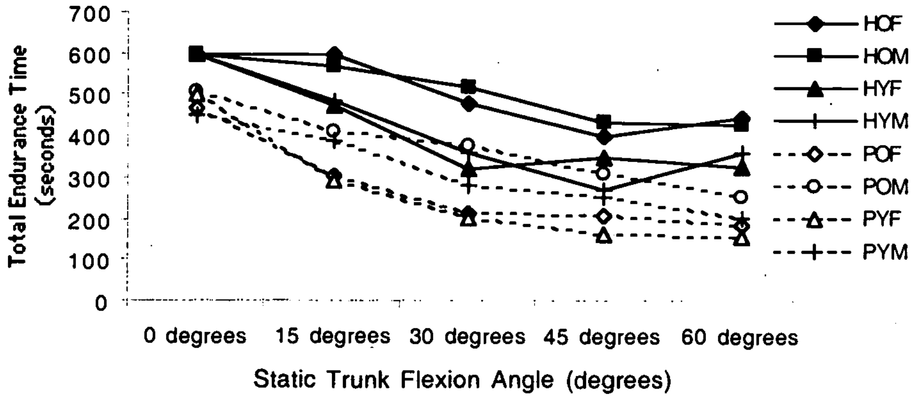


**Figure 1. Total Endurance Time (TET) in Static Trunk Flexion Postures**

Table 1 shows the mean TET summarized for the two populations based on low back status.

**Table 1 Overall Mean Total Endurance Time (TET) by back status**

| Low Back Status | Mean TET (seconds) vs. Static Trunk Flexion Angle | | | | |
|---|---|---|---|---|---|
| | 0° | 15° | 30° | 45° | 60° |
| Healthy | 599 | 533 | 418 | 366 | 389 |
| Back Pain | 479 | 345 | 268 | 234 | 200 |

The following trends were observed:

- Persons with back pain had lower endurance times at all angles of trunk flexion when compared to those with healthy backs. The difference was most pronounced at the 60° flexion angle, where TET for back-pain subjects was only 51% of TET for healthy subjects.

- For all subjects, TET decreased with increasing angle of static trunk flexion. This drop was most pronounced from 0° to 30°. In those with back pain, the drop in TET was significant ($p<0.05$) between the neutral position (0°) and all other angles. In the population with healthy backs, there was a significant drop in TET between 15° and 30° ($p<0.05$).
- While not statistically significant, males with chronic back pain had longer endurance times than females with chronic back pain.
- While not statistically significant, older subjects with healthy backs had longer endurance times than younger subjects with healthy backs.

## DISCUSSION

Our results show a decrease in postural endurance capacity in persons with chronic low back pain. Persons with chronic back pain have lower TET at all trunk flexion angles compared to those with healthy backs. This knowledge can potentially be applied in the functional assessment of low back pain patients, such as to monitor improvement during therapy.

Task effects (flexion angle) are significant; TET decreases as the flexion angle increases in both healthy persons and those with chronic back pain. However, this decrease is different for the two populations. For those with chronic back pain, even the smallest amount of trunk flexion causes a significant drop in postural endurance time. In the population with no back disorders, there is a significant drop in TET only when flexion exceeds 15°. These results draw attention to the importance of work station layout and job design, particularly for persons with chronic low back pain. A job that requires even the slightest amount of trunk flexion could lead to significant fatigue and possibly exacerbate a pre-existing back condition. Thus job modification and accommodation is vital in the treatment and rehabilitation of workers with chronic low back pain.

Non-significant age and gender trends were also observed, with different effects depending on back health status. Among back pain subjects, males outperformed females, while among healthy subjects, the older population outperformed the younger. Additional research involving a larger sample size is needed to address age and gender effects.

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# ASSESSMENT OF POSTURE-INDUCED DISCOMFORT IN SUSTAINED AND REPETITIVE NONNEUTRAL TRUNK POSTURES

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## ABSTRACT

Nonneutral trunk postures in the workplace can cause fatigue and contribute to the development of low back pain. A laboratory study was conducted to determine the effects of personal (age, gender and back disability status) and task factors (flexion angle and work-rest cycle) on perceived discomfort in the lower back during static and dynamic trunk flexion tasks. Results show that persons with chronic back pain report higher levels of discomfort than their healthy counterparts. Discomfort is also affected by trunk flexion angle and the work-rest cycle.

## BACKGROUND

The relationship between back pain and posture is complex. An early symptom of work-related soft tissue disorders is the perception of fatigue and discomfort (1). Understanding the discomfort response to the static and dynamic postural demands of work can provide important information for job designers and for the rehabilitation of workers with chronic low back pain. Nonneutral trunk postures such as forward flexion, twisting and lateral bending causes increased activity in the erector spinae muscles and tension on non-contractile tissue that may lead to fatigue and discomfort. During static exertions, subjective reports of discomfort increase significantly with increasing trunk flexion (2). In dynamic postural tasks, EMG studies have shown that the work rest cycle is a factor in the development of muscular fatigue (3). In this paper, we present results from our study of perceived discomfort in the low back following static and dynamic trunk flexion tasks in a population with chronic low back pain and a healthy control group.

## RESEARCH QUESTIONS

Our study addressed the following questions: 1) Among people with chronic back pain and those with healthy backs, which personal and task factors affect perceived discomfort during static and dynamic trunk flexion, 2) What is the nature of this relationship, and 3) How can this information be integrated into clinical evaluation for intervention and accommodation of workers with chronic low back pain?

## METHOD

80 subjects, 40 males (M) and 40 females (F), from two age groups, 20 to 40 years (Y) and over 50 years (O), took part in the study. Of these, 40 were diagnosed with chronic low back pain (P) lasting at least 3 months or more, and the remaining 40 had healthy backs (H). There were 10 subjects in each of the eight age/gender/back strata: HOF, HOM, HYF, HYM, POF, POM, PYF, and PYM. Subjects performed dynamic and static trunk flexion tasks. For the dynamic tasks, the independent variables included four trunk flexion angles (15°, 30°, 45°, and 60°) performed at two work-rest duty cycles (80% work with 20% rest, and 60% work and 40% rest). The static tasks required sustained trunk flexion at 0°, 15°, 30°, 45°, and 60°. In both the static and dynamic tests, subjects were instructed to perform the required exertion until they reached their maximum pain tolerance limit, or for a maximum duration of 600 seconds, whichever occurred sooner. At the end of each

exertion, subjects used a Visual Analog Scale (VAS) to rate discomfort at 11 different body locations, including the lower back. In this paper, we focus on discomfort at the lower back.

## RESULTS

Figure 1 summarizes the results of discomfort in the lower back for the 80 subjects. The discomfort score is plotted as a function of trunk flexion angle for each of the eight age/back status/work-rest cycle stratum. Persons with healthy backs are shown with solid lines while persons with chronic back pain are shown with dotted lines.

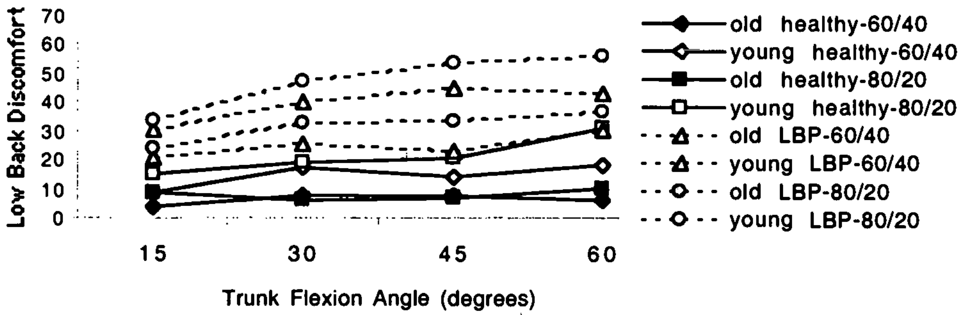


**Figure 1. Rating of low back discomfort following dynamic trunk flexion.** Low back discomfort score is distance (mm) on 10-point Visual Analog Scale where 0 mm= "No Discomfort" and 100 mm = "Extremely Uncomfortable". Numbers for each stratum refer to the work rest cycle, i.e. 80/20 means 80% trunk flexion with 20% recovery in a neutral posture.

Figure 2 shows the discomfort rating following static trunk postures for each age/gender/back status stratum. Dashed lines represent persons with low back pain.

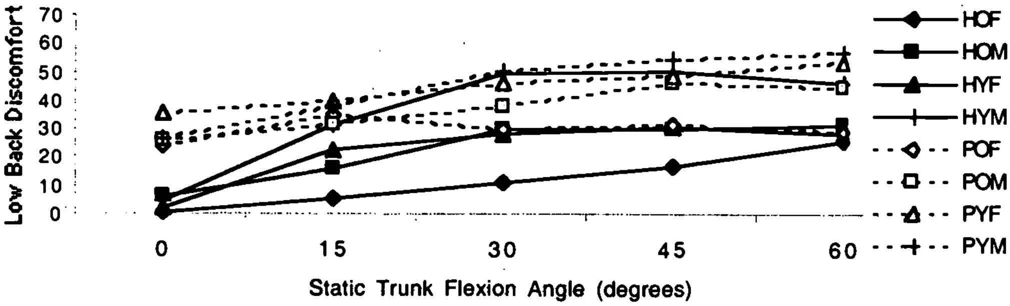


**Figure 2. Rating of low back discomfort following static trunk flexion.**

The following trends were observed:

- In both dynamic and static trunk flexion tasks, subjects with chronic low back pain experienced higher levels of discomfort in the lower back than those without back pain. However this difference is significant only ($p<0.05$) for the dynamic tasks.
- In all subjects, low back discomfort increased with increasing trunk flexion angle during static exertions. However, pairwise analysis showed that this difference was only marginally significant ($p<0.1$) between 0° and all the other angles.
- Younger subjects reported higher levels of discomfort than older subjects.
- For dynamic tasks, duty cycles requiring 80 percent work (80/20) resulted in higher levels of perceived discomfort than duty cycles requiring 60 percent work.

## DISCUSSION

Our results show that persons with chronic low back pain have higher levels of self-reported discomfort in the low back compared to those with healthy backs after performing both static and dynamic trunk flexion tasks. Regardless of back health status, perceived discomfort increased as a function of the trunk flexion angle. This finding has practical implications. Jobs that require even minimal levels of trunk flexion (only 15°) can produce perceptible levels of low back discomfort in both healthy workers and those with chronic back pain over time periods as short as 10 minutes (600 seconds). These results draw attention to the importance of appropriate job design, particularly for accommodating workers with chronic low back pain

The work-rest cycle is another factor that must be considered during both job design and placement. Comparing Figures 1 and 2, tasks that required purely static exertions produced higher levels of perceived discomfort for a given trunk flexion angle than tasks that required dynamic exertions. This finding was observed in both healthy subjects and those with chronic back pain. Considering dynamic work activities (Figure 1), tasks that allow longer recovery times (40 percent rest) produced lower levels of discomfort than tasks with shorter recovery times. These findings are important both for primary prevention of back pain (reducing the onset of back pain in healthy workers) and for accommodation. In particular, persons with chronic back pain may have more difficulty with jobs that require prolonged static trunk flexion or to dynamic jobs with insufficient recovery time in the neutral trunk postures.

Age effects were observed for both dynamic and static exertions, with older subjects reporting less discomfort than younger subjects. This finding may have been caused by selection bias (i.e., the older subjects who volunteered for this study were more motivated to score well on the tests than their younger counterparts). It may also indicate that older persons perceive pain differently than younger persons. Further research is needed to fully interpret these findings.

This study showed that perceived discomfort in the lower back during trunk flexion is affected by both personal and task factors. Perceived discomfort can be used as a tool to compare different job designs in order to accommodate workers with chronic back pain.

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# Head Reactions to Platform Movement During Postural Control Tests

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## ABSTRACT

In standing, healthy young adults, postural reactions to small translational perturbations of 4, 16, and 64 mm have been studied to investigate the relative anterior-posterior movement of the head with respect to the translational movement of the feet. This information was then used to determine if the head needs to be included as a separate link in kinematic models that that describe responses to small translational perturbations.

## BACKGROUND

Control schemes for postural stability are very complex. Postural reactions result from the integration of several inputs including tactile, proprioceptive, vestibular, and visual; yet, the systems that control posture cannot be easily inferred from postural reactions alone (1-4). Ankle and hip control strategies are known to play important roles in postural stability (2-4), as is the coordination among these joints and the head and neck positions (5,6). These strategies have been studied using kinematic models. A traditional one-link model considers a pivot point at the ankle; while the two-link model adds motion about the hips. The effect of head and neck movement has been considered in only a few studies (5,6).

In assessing postural stability, a variety of techniques have been employed to measure head motion. Shelfon (7) used a pen attached to the forehead to trace lateral sway. Hirasawa (8) photographed or video recorded movements of light emitting diodes fixed at various positions including the head. Other studies have used visual markers to study the movement of the head. These studies looked at sway rather than the effect of head position on the stability of posture during movement.

Our laboratory focuses on the psychophysics of postural stability, as we look at displacement perturbations that are very small and that are within the range of normal sway pattern length. We have in our laboratory a platform on which a standing person is subjected to vibration-free translations as small as 0.1 mm (9). We found a logarithmic relationship between the distance traveled and the peak acceleration reached in determining thresholds. The system is the Sliding Linear Investigative Platform for Analyzing Lower Limb Stability (SLIP-FALLS) designed by Robinson, *et al.* (10).

## RESEARCH QUESTION

The objective of this study is to look at head displacement with respect to feet displacement during perturbation testing. Since the feet are standing on the anteriorly translating platform, the displacement of the platform and the feet are identical. From the cross correlation of the head and platform movements, the type of model necessary to explain the reaction to a perturbation can be determined.

## METHOD

The Sliding Linear Investigative Platform For Analyzing Lower-Limb Stability (SLIP-FALLS) is utilized in testing subjects. The key feature of this platform is its ability to maintain exceedingly precise position control within ± 5 micrometers (9,10). Subjects are blindfolded; and masking noise and computer-generated verbal commands are telemetered to earphones worn by the subject.

During testing, the plate acceleration is measured by a uniaxial accelerometer attached to the plate (sensitivity 0.02G/V, resolution 0.01G). The head acceleration was measured by a tri-axial accelerometer (Analog Devices ADXL05 EM-3, packaged by NeuGhent Technologies as part TAA-31013, sensitivity 0.02G/V, resolution 0.01G). This accelerometer in turn is attached to the right side of the earphones and two small spirit levels attached to the accelerometer case allow us to align the z axis perpendicular to the plane of motion (10). A LabVIEW program uses the tri-axial acceleration data to determine head motion during the perturbation. The head motion in the direction of plate motion is cross-correlated with the plate motion. Other measurements include the anterior-posteror (AP) and medial-lateral (ML) center of pressure, and surface EMG signals from the gastrocsoleus and the tibialas anterior (TA) muscles of both legs.

Acceleration detection threshold is determined using a Parameter Estimation by Sequential Testing (PEST) technique where the peak acceleration of the platform is modified from trial to trial based on the correctness of the previous two or three trials. For a given displacement (4, 16, 64 mm), up to thirty trials are used. Each trial consists of a 4s baseline interval, followed by two 4s test intervals, and lastly a 4s decision interval. A Two-Alternative-Forced-Choice paradigm forced subjects to signal during the decision interval whether a forward translation occurred in either the first or second test interval. The baseline interval is used to record the pre-move profile of the AP and ML Center-of Pressures, the acceleration of the head, and the TA and Gastrocsoleus EMGs. Masking noise, voiced commands, and the decision tone pulse(s) are provided to the blindfolded subjects via the earphones. No feedback is provided as to the correctness of the response. The acceleration profile is smoothed to reduce jerk. Six male subjects, between 22 and 31 years old, with no known neurological or vestibular deficit, participated in this study. The last eight trials for each displacement were analyzed since the PEST method yields convergence in these trials to peri-threshold levels.

## RESULTS

Figure 1 shows the cross correlation of head and plate position for a male, aged 24, with the data taken from the thirteenth of 20 trials in a series of 64 mm translations. The lag (or lead) of the head to the plate motion was determined from the cross correlation. The lags were divided into two categories: <5 ms (72% of 144 observations) and >5 ms (28%). The lags were then paired with the trial number. The alternative hypothesis states that there will be an increase in the lags as the trial number increased and the subject reaches their threshold. A Kruskal-Wallis One Way ANOVA was then conducted. The resultant statistics can be seen in Table1.The probabilities calculated here assume a Chi Square distribution with seven degrees of freedom.

*Figure 1: Sample Cross Correlation of Head Position and Platform Position*

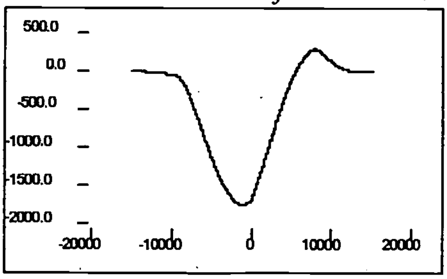


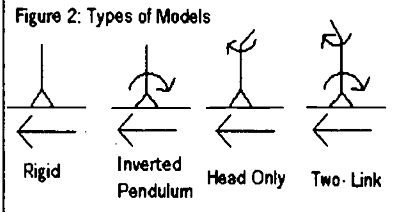

*Table 1: Statistical Analysis of Lag Time at Threshold Level*

| Movement Length | Number of Cases | Kruskal-Wallis Test Statistic | Probability |
|---|---|---|---|
| 4mm | 6 X 8 | 4.754 | 0.69 |
| 16mm | 6 X 8 | 6.015 | 0.538 |
| 64mm | 6 X 8 | 4.809 | 0.683 |
| All groups | 144 | 3.519 | 0.833 |

## DISCUSSION

Responses to perturbations can be represented by several different models. The simplest is a rigid model and the most used is an inverted pendulum model. These can be seen in Figure 2. Other models shown in Figure 2 include head motion only and a two-link model that has pivot points at the ankle and at the neck. The data from the cross correlation of the head and the plate displacement showed that 103 of the 144 trials exhibited no lag. This indicates that the rigid model best describes the response of the subject to small translational movements because as the plate moved, the head followed at the same time in the same direction. For the other 41 trials, head motion either led or lagged plate motion indicating that one of the other models is more appropriate.

Figure 2: Types of Models




The lack of lag between the head and the feet might well be due to the very small movements and smooth acceleration profiles. The translations are near the perception level of the subjects and the two-alternative-forced choice testing method forces the subject to concentrate on any cues that might indicate that a movement has occurred. The detection latencies indicate that subjects are probably using other cues (possibly proprioceptive or kinesthetic) for that determination. Therefore, motion of the head is not usually used as a cue for linear movement detection at small displacements.

Further work should investigate the location of the center of pressure (COP) at the time of the movement, and the cross correlation of the COP and head position. These measurements may give a better indication of the role of head movement in detecting small translational movements.

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# MEASURING SHOCK ABSORPTION OF LOWER LIMB AMPUTEES

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**ABSTRACT**
Impact of the tibia at heel strike has been shown to contribute to degenerative diseases (1). Amputees have a greater incidence of osteoarthritis (2) due to asymmetric gait, but little has been done to examine the impact during heel strike of these subjects. We examined two transfemoral and one transtibial adult during walking to examine the differences in impact between the affected and the unaffected limbs. We found significant differences in peak impact acceleration and heel strike transient amplitude. By using this technique to evaluate heel strike impact in a clinical setting, we will be able to complement the expertise of the prosthetist in the choice of the prosthesis and reduce the possibility of developing degenerative joint diseases.

## BACKGROUND

It has been shown that 25% of the impact on the shank during heel strike travels to the head through the back (3). All patients with degenerative diseases such as osteoarthritis have insufficient shock absorber capacity (1). Poor attenuation in one knee leads to changes in the walking pattern. Overloading of this knee can result in subchondral bone microfractures leading to articular cartilage degradation (1). Amputees have been shown to have greater incidence of osteoarthritis and those with transfemoral amputations are three times more likely to exhibit this condition at the hip than a transtibial amputee (2).

A number of studies have used orthotics to decrease the shock through the tibia (4,5). Wosk and Voloshin (4) used viscoelastic shock absorbing shoe inserts to show that maximal amplitudes of bone oscillation were reduced and an improvement in pain syndrome of the back resulted. To date, no studies have evaluated subjects with lower limb amputations or congenital disorders in an attempt to reduce impact by using different prostheses.

Measurement of impact is typically performed using accelerometers (1-9). Many of these impact tests have been performed on elite athletes to characterise running gait. In a clinical setting, Retschko *et al.* (5) evaluated impact differences in normal subjects at the tibia between orthotics made from weightbearing and non-weightbearing techniques. If prostheses with shock absorbing characteristics are identified for each unique client in a clinical setting, we may be able to use this method to complement the expertise of the prosthetist to reduce impact forces and the probability of developing degenerative joint diseases.

## OBJECTIVE

The objective was to examine differences in accelerometer data between the affected limb and unaffected limb of subjects with a unilateral amputation.

## METHOD

An Analog Digital XL202 accelerometer was mounted along the axial direction of the tibia (unaffected limb) or on the prosthetic pylon (affected limb) and a DAS20-Bipolar SW Program Gains +/-10 V data acquisition card collected data at 1000 Hz for ten steps. The maximal acceleration at heel strike and the amplitude of the heel strike transient was measured for each step (Figure 1). To avoid anomalies, three values at each maximal and minimal peak for heel strike were averaged to give maximal and minimal values used in statistical analysis. A paired t-test was conducted between the two limbs of each patient.

Three subjects with unilateral amputations were involved in the barefoot testing. One subject (S1) had a PFFD with a Tih-Lin knee and a Masterstep foot. The second wore an Otto Bock 3C100 C-Leg with Otto Bock's 1C40 C-Walk foot (S2). The third subject had a transtibial amputation and also wore Otto Bock's 1C40 C-Walk foot (S3).

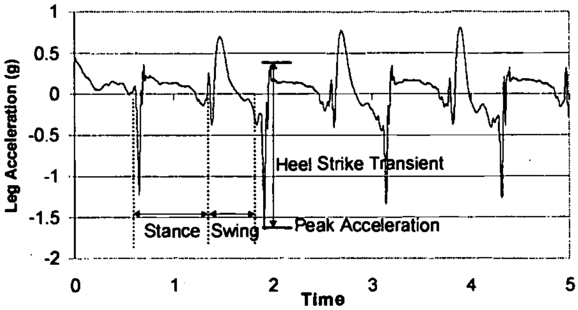


Figure 1: Typical acceleration results for a prosthetic limb.

## RESULTS

Peak heel strike acceleration of the unaffected limb was significantly greater for subjects S1 and S3 (Figure 2), whereas S2 had significantly lower heel strike measurements for the unaffected limb.

Heel strike transient amplitudes of the unaffected limb of S1 and the affected limb of S2 were also significantly greater than the contralateral limb.

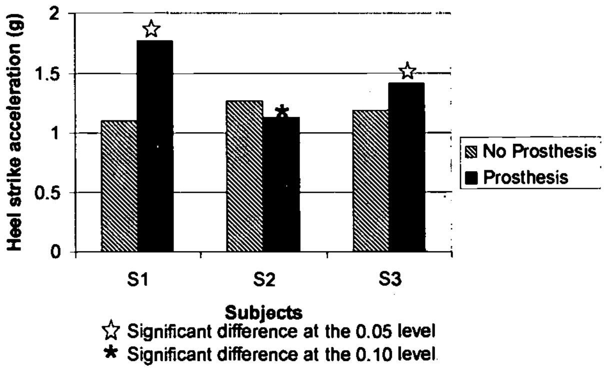


Figure 2: Peak acceleration at heel strike.

## DISCUSSION

The results of this study indicate that accelerometers can be used to measure the transmission of shock in the axial direction through the tibia or through the prosthetic pylon of subjects with lower limb amputations. Significant differences were evident for both the heel strike transient amplitude and the peak acceleration. In the past, skin mounting has been shown to exhibit slightly higher acceleration measurements than bone mounts (6) although the correlation between the two is greater than 0.85 (7). A mount to the pylon can be paralleled with bone mounting, as no additional artefacts are introduced. Increased impact on the affected side was evident (for S1 and S3) even under these conditions.

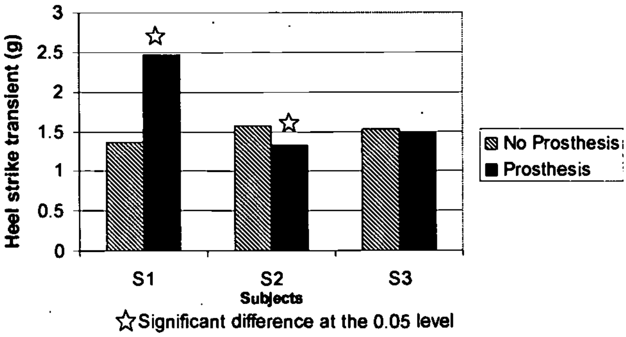


Figure 3: Average heel strike amplitudes.

S1 exhibited higher peak heel strike acceleration values and higher heel strike transient amplitude for the affected limb. The asymmetric motion of subjects with transfemoral amputations occurs as the subject locks the leg in full extension prior to heel strike. This slowing down of the prosthetic leg and the initial weight acceptance caused higher impact.

S2 was wearing an Otto Bock 3C100 C-Leg and the results showed that the affected side had greater peak impact and amplitude than the unaffected limb. This single axis leg is controlled by a microprocessor. Force sensors in the shin determine heel and forefoot loading stance phase stability and adjust automatically to different conditions. This microcontroller allows for reduced impact at heel strike.

The higher peak acceleration of the transtibial subject (S3) indicates that the prosthetic foot is not as effective as a shock absorber as the adipose tissue of the heel pad of the unaffected foot. This rapid deceleration impulse peak may cause shear stress in the spinal facet and sacro-iliac joints leading towards degeneration in these areas (8). The heel strike amplitude was not significantly different between the two legs indicating a trend towards lower loading during remaining stance phase.

Analysis of these three subjects showed that accelerometers could be used to measure impact acceleration of lower limb amputees. This technique will be used in a clinical setting to evaluate knee and foot prosthetics to reduce impact for each individual. One child has been evaluated using this method to evaluate different prosthetic feet, and these results have been submitted to the Association of Children's Prosthetics and Orthotics Clinics Conference (9).

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# STUDY ON SEVERITY OF VISION LOSS AND CLIENT SATISFACTION AND PERFORMANCE

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## ABSTRACT

Residual functional vision and priority tasks in reading and writing are individual to each client. This study attempts to quantify the severity of vision loss and correlate this with client satisfaction and performance in reading and writing tasks after the acquisition of assistive technology, as measured with the Canadian Occupational Performance Measure. Almost all clients reported significant improvements in satisfaction and performance, however, clients with mild and severe vision loss reported more significant improvements than clients with moderate vision loss. Clients with moderate loss had the highest variability in scores. Discussion is offered on the difficulties this group encounters in utilizing assistive technology in reading and writing tasks.

## BACKGROUND

In the United States, over 6 million persons are visually impaired, and another one million classified as "legally blind", having a best corrected visual acuity of 20/200 or less in the better eye, or a visual field of 20 degrees or less (1). The term "low vision" covers a wide range of visual impairment, from near normal vision in the early stages of an eye disease to moderate or severe loss. Performance varies with each individual, who may experience cloudy vision, constricted fields or large scotomas. (1) While best corrected acuity, visual fields, contrast sensitivity, color perception and glare sensitivity all impact on daily function and reading ability, acuity remains the measurement most consistently used in medical records and referral data obtained for assistive technology assessments. Colenbrander, Leigner and Fletcher developed a system grouping visual acuity levels into ranges of visual loss and correlating this with estimated reading ability and reading devices required for function (2). These ranges of losses were used to group clients at the Vision Technology Service (VTS) of the Adaptive Technology Resource Centre into Mild (1-5), Moderate (6-7) and Severe (8-10) vision loss, as described in Table 1.

| VTS Assigued Numeric Score | Visual Loss | Ranges of Visual Loss | Visual Acuity |
|---|---|---|---|
| 1 - 4 | (Near) Normal Vision | Range of Normal Vision | 20/12 to 20/25 |
| 5 | | Near-Normal Vision | 20/30 to 20/60 |
| 6 | Low Vision | Moderate Low Vision | 20/80 to 20/160 |
| 7 | | Severe Low Vision | 20/200 to 20/400 |
| 8 | | Profound Low Vision | 20/500 to 20/1000 |
| 9 | (Near) Blindness | Near-total vision loss | 20/1250 to 20/2500 |
| 10 | | Total Blindness | NLP (No Light Perception) |

**Table 1: Numeric score correlation with level of visual loss and acuity level**

The Assistive Devices Program (ADP) of the Ontario Ministry of Health funds devices for personal use of individuals with impaired visual function, usually identified by acuities of 20/80 or worse. At the VTS, the COPM is routinely used in to identify needs in the vision technology assessment and as an outcome measure on follow up. Changes in client ratings of their initial

## RESEARCH QUESTION

While assistive technology theoretically has the capacity to fully support reading and writing tasks, the practical application is threatened by the complexities of the assistive technology hardware and software, client barriers to learning and sometimes lack of environmental supports. The simplest products are CCTVs and magnification software, usually used by those with the least vision loss. People with severe vision loss and blindness use the most complex and memory intensive products such as screen reading and OCR software. The question examined was to determine whether there were differences in the mean COPM outcome measure scores between groups of clients with mild, moderate and severe vision loss. The outcome would possibly indicate how perfectly the technology could compensate for all levels of visual impairment, or conversely, which group(s) is worse served by the existing technology or has the greatest difficulty using it with their level of vision loss.

## METHOD

With the assistance of two University of Toronto occupational therapy students, the level of acuity recorded in client charts was assigned a numeric score indicating level of vision loss. The students also assisted in follow up procedures from January to June 2000. The level of vision loss was then examined in correlation with the follow up performance and satisfaction data obtained with the Canadian Occupation Performance Measure (COPM) scores. Forty-eight clients with complete records were selected for this study. Twenty-seven clients were male and 21 were female, with an average age of 40.3 years. Table 2 displays the breakdown of each of the most common diagnostic groups with the range of vision loss in this sample. Only 5% of the clients studied had a classification of 1 – 5, 41% had moderate vision loss of 6 – 7, and 54% had severe visual loss in the 8 – 10 range.

| Level of Vision Loss | 1 to 5 | 6 to 7 | 8 to 10 |
|---|---|---|---|
| Diabetic Retinopathy | 0% | 0% | 100% |
| Glaucoma | 0% | 60% | 40% |
| Macular Degeneration | 0% | 18% | 82% |
| Nystagmus | 0% | 50% | 50% |
| Optic Atrophy | 0% | 75% | 25% |
| Other | 8% | 58% | 34% |
| Retinitis Pigmentosa | 20% | 60% | 20% |

Table 2: Percentage of Diagnostic group in each Level of Vision Loss

## RESULTS

The results, as shown in Table 3 and 4, indicate that the mean COPM scores were significant and almost unchanged across the levels of visual disability. The greatest ranges in performance and satisfaction scores were found in the moderately impaired group, which also had more non-significant scores than the other two groups.

Severity of Vision Loss and Client Satisfaction and Performance

| Level of Vision Loss | Mean | Upper Range | Lower Range | Significant | Non-significant |
|---|---|---|---|---|---|
| 1-5 | 5.4 | 5.5 | 5.3 | 100% | 0% |
| 6-7 | 5.1 | 9 | 0 | 94% | 6% |
| 8-10 | 5.1 | 8.5 | -0.5 | 98% | 2% |

**Table 3: Changes in Pre/Post COPM Performance**

| Level of Vision Loss | Mean | Upper Range | Lower Range | Significant | Non-significant |
|---|---|---|---|---|---|
| 1-5 | 5.2 | 8 | 2.3 | 100% | 0% |
| 6-7 | 5.1 | 9 | -1.3 | 88% | 12% |
| 8-10 | 5.2 | 9 | -0.3 | 97% | 3% |

**Table 4: Changes in Pre/Post COPM Satisfaction**

## DISCUSSION

While this study draws on a small sample size, the results indicate the least significant changes in client satisfaction and performance can occur among those with moderate vision losses, with acuity levels from 20/80 to 20/400. Clinically, this group generally relies on screen magnification products, usually with text to speech support, or CCTVs. They continue to utilize their vision instead of relying on the memorization of keystrokes and auditory feedback of screen reading or OCR products. Those at the most severe end of the range, in particular, encounter difficulties as they attempt to perform reading and writing tasks at 4 to 10 times magnification and greater. While it is encouraging to note that a high mean change in satisfaction and performance was experienced at all levels of vision loss, greater effort in assistive technology development and client education may be needed to support clients with moderate vision losses.

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# DEVELOPMENT OF AN OUTCOME MEASURE TOOL FOR WHEELCHAIR SEATING & MOBILITY INTERVENTIONS: A WORK IN PROGRESS

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## ABSTRACT
The purpose of this project is to develop an outcome tool to measure the effects of wheelchair seating and mobility interventions on functional capabilities specific to consumer needs. The Functional Evaluation in a Wheelchair (FEW) Tool is undergoing systematic development in three phases. This paper will present the methodology of the phases and results of Phase 1.

## BACKGROUND
Clinicians who provide wheelchair seating and mobility interventions are faced with the need for evidence based outcomes. Clinicians generally do not have the time, skills or support of administration to participate in research or outcomes data collection as part of usual care. Nor are there instruments that specifically measure the outcomes of seating and mobility technology interventions (1). Consumers also do not have a means of measuring the effectiveness of equipment in meeting their needs. Likewise, funding sources do not have an objective means of determining the cost/benefit of the equipment they are asked to pay for. For this reason, clinicians, researchers, and consumers in the Rehabilitation Engineering & Research Center on Wheeled Mobility & Seating at the University of Pittsburgh have embarked on a study to systematically develop a new outcomes measure (2). The goal is for the measure to be concise and easy for service providers to administer and focus on function affected by wheelchair and seating system technology, as perceived by consumers. The measure will also serve to assist in the documentation and justification of the effectiveness of new wheelchair and seating systems. Furthermore it should validate the quality of the product and the need for a systematic assessment process.

## DESIGN
The FEW will be designed as a questionnaire that will be administered over time to consumers of wheelchair and seating system technology, as a dynamic indicator or profile of perceived function related to wheelchair use. The study will be conducted in three phases over a period of 5 years. The objectives of Phase 1: (a) select and evaluate existing functional measurement instruments with relevant factors (i.e., function, posture, quality of life, and satisfaction) to wheelchair users, (b) conduct videotaped interviews with 20 manual and powered wheelchair users with various causes of disability to determine what functional tasks are important for them to perform while seated in their wheelchairs, and (c) develop the items for the new outcome measure. The objectives of Phase 2: (a) determine internal validity and test-retest reliability of the FEW, (b) compare the relationship of the FEW to other functional measurement instruments, and (c) use Rasch Analysis to evaluate the new outcome measure. Phase 3 consists of clinical trials to determine if the FEW is capable of detecting changes in function, following acquisition of a new wheelchair and seating system.

## DEVELOPMENT & EVALUATION
Phase 1: Item Development

Phase 1 Item Development consisted of several incremental tasks. First, existing functional measurement instruments were evaluated based on purpose, question content and format, and scoring criteria to establish the availability of instruments that measured constructs similar to the FEW, and to assist in the development and scoring of the FEW items. Next, trained interviewers administered a modified version of the Canadian Occupational Performance Measure (COPM) (3). The COPM is a client-centered outcome measure that uses a semi-structured interview format with a structured scoring method to detect changes in self-perception of occupational performance over time (3). Inter-rater reliability was conducted by randomly selecting 3 of the 20 videotaped interviews. The interviews were independently rated by two observers for agreement of content and agreement of rank order, and then compared to the interviewer's documented Modified COPM. Percent agreement among the three raters ranged from 100% for content to 95% for rank order. The Modified COPM requires participants to rank (1 highest to 10 lowest) the importance of each reported task or activity into three categories: (1) self-care (i.e., personal care, functional mobility, and community management), (2) productivity (i.e., paid/unpaid work, household management, and play/school), and (3) leisure (i.e., quiet recreation, active recreation, and socialization). The consumers reported a total of 154 items across the three COPM categories: self-care (n = 58), productivity (n = 39), and leisure (n = 57). Duplicate items within single categories were eliminated, and similar items across all categories were combined. Based on the consumer ranking of the items in each category, a reverse ranking system (10 highest to 1 lowest) was used to assign a weighted value to each item across all responses. The frequency of response and weighted values assigned by the consumers were then multiplied to yield a weighted rank order (WRO) for each item. Next, the WROs for all items were sorted to identify the items of highest priority and lowest priority. Items were then coded into categories. Two clinicians then sorted all items into 21 categories derived from literature searches and the review of other functional assessment tools. The members of the research team then reviewed all items and by consensus reallocated them into 10 new categories (see Table 1). As part of the validation study, consumer participants will receive a questionnaire asking them to rank order the importance of each new category for function related to their wheelchair mobility and seating systems. They will also be asked to complete Version 1.0 of the FEW and provide feedback about wording of the items, content of each item, and the scaling system. Version 1.0 of the FEW consist of 10 questions in the following format: My seating/mobility system allows me to...(1) do tasks at different surfaces, (2) get around the environment in the presence of physical barriers or obstacles, (3) do what I want to do when I have to reach from my chair, (4) transport my chair wherever I want to go, (5) make my chair do what I want it to do and where I want to do it, (6) transfer from one surface to another surface, (7) do what I want to do with the accessories that are attached or mounted to my chair, (8) get around outdoors over obstacles and uneven ground, (9) ride public transportation, and (10) secure my chair during transportation. A 6-point scale is used for responses: completely agree, mostly agree, slightly agree, slightly disagree, mostly disagree, and completely disagree. Consumer participants will also be asked to provide feedback on aspects of wheelchair and seating systems that are important, but were not included in Version 1.0 of the FEW.

Phase 2: Test Evaluation

Twenty consumers of existing wheelchair and seating technology who have non-progressive conditions will be recruited for Phase 2. The FEW will be administered at two separate times at least 24 hours apart to examine the test-retest properties of the outcome measure.

Phase 3: Clinical Trial

Phase 3 of the study will be conducted in coordination with the University of Pittsburgh Medical Center (UPMC) Center for Assistive Technology (CAT). Consumers with non-progressive conditions who have been referred to the Center for a wheelchair evaluation (cannot be the persons' first wheelchair) will be administered the FEW during their initial evaluations, and then at 1 week and 3 months after the new wheelchair has been received. This process will determine the ability of the FEW to detect differences over time and with various mobility/seating systems.

**Table 1 FEW ITEM CATEGORIES**

| | |
|---|---|
| 1. Accessing Task Surfaces | 6. Accessories |
| 2. Architectural Barriers | 7. Natural Barriers |
| 3. Reach | 8. Transportation: Accessibility |
| 4. Human-Machine Interface | 9. Transportation: Securement |
| 5. Transfers (lateral, forward, sit to stand) | 10. Transportation: Portability |

## DISCUSSION

The data gathered from the interviews and the questionnaires has generated important information concerning the relevance of functional tasks for wheelchair users and their mobility/seating systems. Twenty wheelchair users identified a 154 occupational performance issues with the greatest concern or dissatisfaction in the performance of self-care, leisure, and productivity tasks. The top 3 categories with the highest WRO values showed manual and power wheelchair users experienced the most task or activity impediments to function when accessing task surfaces, encountering architectural barriers, and reaching from their seating/mobility surface. The findings demonstrated a need to further study and evaluate the needs and abilities of the consumers in regard to provision of the most appropriate technology to improve or maintain function. It is important to measure outcomes in the context of consumers' specific abilities to perform functional activities in their own environments based on their own performance goals. With outcome data that supports the functional value of seating and mobility systems, persons with disabilities may experience fewer problems with obtaining funding, and experience greater satisfaction and improved quality of life with wheelchair and seating technologies that maximize performance in life roles. The development of the FEW instrument should yield a valid outcome measurement tool that will help to validate the cost effectiveness and functional value of wheelchair and seating systems to the consumer.

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# PSYCHOSOCIAL IMPACT OF ELECTRONIC AIDS TO DAILY LIVING

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## ABSTRACT

Psychosocial impact is a significant determinant of how users perceive the benefit of assistive devices to their quality of life. This study compared the perceived psychosocial impact of electronic aids to daily living (EADLs) of a group of device users with the anticipated impact of EADLs reported by a group who were eligible for, but had not yet received, these devices. EADLs were found to produce similar degrees of positive impact on users and positive perceptions of anticipated impact on those without devices. The psychosocial impact on users was stable over time. The results indicate that the perceived benefits of EADLs to the autonomy, functional independence, and psychological well being of both users and nonusers are positive and strikingly similar.

## BACKGROUND

Electronic aids to daily living (EADLs) are an important category of assistive technology whose contributions to functional and psychosocial outcomes have not been well researched. EADLs can be defined as electronic devices that are used to access, operate and control technologies for comfort, communication, leisure and personal security (1). Formerly known as environmental control devices, EADLs allow persons who have a severe physical disability alternative access to a wide variety of household and workplace appliances, independent of assistance from family members or other caregivers. EADLs are normally prescribed for persons whose disability severely restricts their functional independence, as a means of improving their opportunities to engage in daily activities of their choice, and freeing their caregivers to do other things (2). As it is necessary to choose from among several service options, reflecting a wide range in cost, it has become very important to know what sorts of outcomes are typically associated with the options of choosing or not choosing an EADL.

Here we report on the impact of EADLs on psychological well being and its relationship with perceived quality of life for persons who have a degenerative neuromuscular condition using a self-report rating scale. We used a tool specifically designed to measure subjective perceptions of assistive device impact that include effects on independence. The Psychosocial Impact of Assistive Devices Scale (PIADS) (3) is a 26-item, self-rating questionnaire designed to measure user perceptions of how assistive devices affect quality of life. The PIADS describes user perceptions along three dimensions: Adaptability (the enabling and liberating effects of a device); Competence (the impacts of a device on functional independence, performance and productivity); Self-esteem (the extent to which a device has affected self-confidence, self-esteem and emotional well being). Scores can range from –3 (maximum negative impact) through zero (no perceived impact) to +3 (maximum positive impact).

In this paper, we use the term "low technology" to refer to both "no tech" and "low tech" interventions as defined by Lange (5) to include EADL equipment without batteries or electricity, and devices that involve simple technology to either augment direct motor access (e.g,, a switch control for a battery-operated toy) or simplify cognitive requirements (e.g., TV remote control with larger buttons and fewer choices). "High technology" is more sophisticated and includes integrated EADLs used to access, operate and control electronic devices such as telephones, radio-controlled devices, door openers and security systems.

## METHODS

### *Design*

Our study tested the following hypotheses: (1) EADL users report a positive psychosocial impact; (2) the psychosocial impact of EADLs changes over time; (3) the anticipated psychosocial impact of EADLs is different from the impact reported following device adoption. We compared two pre-existing groups of persons who have a degenerative neuromuscular disorder, a group of EADL users and a group with comparable clinical characteristics but who had not yet received EADLs. We defined an EADL user as a person who could reliably control a telephone or emergency alert device and at least one other output technology, as determined by an assistive technology specialist. The user group was interviewed twice over a period of time that ranged between 6 months and 9 months following their initial interview.

### *Sample*

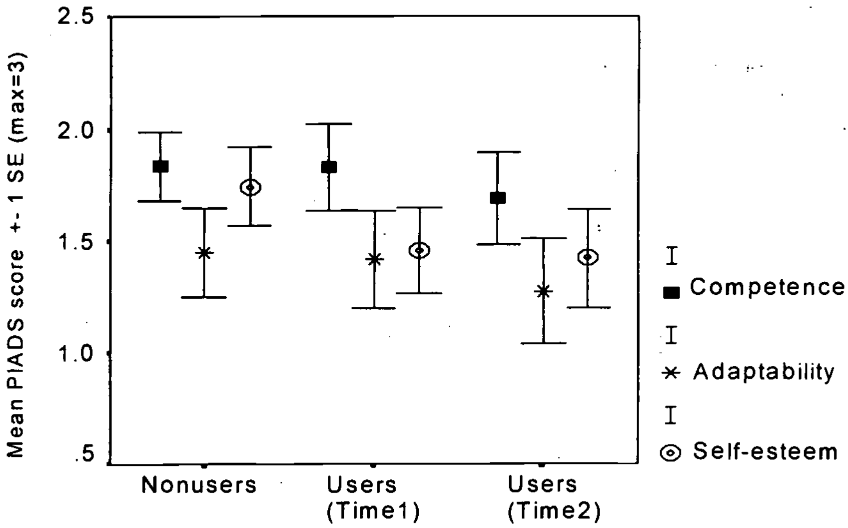
The research participants were forty-one young adults who had been diagnosed as having a progressive neuromuscular condition. They were recruited through assistive technology services located in the greater Toronto area. Most (29/41) had a diagnosis of Duchenne Muscular Dystrophy (DMD). There were 20 participants in the EADL user group and 21 in the EADL nonuser group. All participants were almost completely dependent in occupations of self-care, as observed on the Functional Independence Measure (FIM).

### *Data collection*

The PIADS was administered in a face-to-face interview format by an experienced therapist who was not a service provider to the participant. Four therapists took part in the interviewing (3 occupational therapists and 1 physical therapist). Nonusers were asked to use the PIADS to indicate the anticipated psychosocial impact of using EADLs (4).

## RESULTS

The following figure shows the mean PIADS subscale scores obtained from the groups of participants.



Mean PIADS scores were positive and similar to those reported for high technology devices in other studies, and larger than those obtained from users of low technology devices. A MANOVA confirmed that scores on each of the 3 PIADS subscales remained stable over time (i.e., nonsignificant effect of test period). Pairwise comparisons among the subscales showed that a pattern of significantly higher scores for Competence relative to Adaptability and Self-esteem was also stable. A second MANOVA revealed no significant differences between the PIADS scores of nonusers and those of the user group (first interview). Pairwise comparisons among the subscales showed that for both groups scores on Competence were significantly higher than scores on both Adaptability and Self-esteem. Scores on Adaptability and Self-esteem were not significantly different from each other. Throughout the analyses, we had confirmation that impact was greatest for perceived functional performance (Competence subscale), compared with other psychosocial areas (Adaptability and Self-esteem subscales).

## DISCUSSION

Our research provides good evidence to support the claim that EADLs contribute significantly to the user's perceived functional independence. Moreover, EADLs appear to enhance other important aspects of the user's psychological well being. The positive psychosocial impact reported by EADL users was stable over time. Persons with degenerative neuromuscular conditions who were candidates for but had not yet received EADLs had expectations of psychosocial benefit from these devices that were not different from the impact reported by users. We interpret our finding as evidence that expectant users have realistic expectations of psychosocial impact. The significance of our findings stems from the fact that for people with degenerative conditions the most important reason for introducing assistive technology is often to promote personal autonomy and preserve dignity (6). The economic relevance will be determined by the value that payers, and society in general, put on this goal for rehabilitation.

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# ENDURANCE TIMES FOR MAINTAINING STATIC TRUNK FLEXION POSTURES AMONG HEALTHY WORKERS AND PERSONS WITH CHRONIC BACK PAIN

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## ABSTRACT

Awkward work posture such as sustained trunk flexion can be a factor in the development of lower back pain and can be a return-to-work barrier for persons with chronic low back pain. Information regarding the ability of people to tolerate awkward trunk postures is important in several aspects of injury prevention and rehabilitation. From the job design standpoint, it is important to know the postural endurance capacities of both healthy workers and those with chronic low back pain. From the patient evaluation standpoint, it is important to be able to compare an individual's postural tolerance capacity to population norms during initial assessment and when monitoring progress during rehabilitation. We performed a laboratory study to determine time endurance limits for maintaining static trunk flexion postures in a population with chronic low back pain and in a control population with no back problems. The results of this study are presented in a table that summarizes time endurance limits for various combinations of personal and task factors.

## BACKGROUND

Work-related low back disability affects millions of workers and is responsible for a significant proportion of health care spending and compensation costs. Awkward work posture, such as trunk flexion or twisting has been associated with elevated rates of low back pain (1, 2). Job designers and rehabilitation engineers need information concerning the performance capability of workers to maintain awkward postures such as sustained trunk flexion. Similarly, clinicians and therapists need this information in order to assess a patient's postural tolerance capacity relative to population norms and to monitor progress following the institution of therapy. Total Endurance Time (TET) for maintaining static trunk flexion postures is a simple assessment tool that can be used to measure functional capacity. A laboratory study was performed to determine TET for maintaining static trunk postures in a population suffering from chronic low back pain and a control group with no back problems. The resulting data were used to estimate normative values for various percentiles of both healthy persons and those with chronic back pain.

## METHOD

80 subjects, 40 males (M) and 40 females (F), from two age groups, 20 to 40 years (Y) and over 50 years (O), took part in the study. Of these, 40 were diagnosed with chronic low back pain (P) and the remaining 40 had healthy backs (H). There were 10 subjects in each of the eight age/gender/back status strata (HOF, HOM, HYF, HYM, POF, POM, PYF, and PYM). Subjects with healthy backs were all currently-employed, working at least 20 hours per week, with no history of back pain and no other health conditions to preclude participation. Subjects with chronic low back pain had been diagnosed with low back pain that lasted at least three months, with no history of back surgery, and no other health conditions contraindicating participation. Most of these subjects were on work restriction or currently unemployed due to their back condition.
Five static postures, presented in random order, were tested at 0° (neutral), 15°, 30°, 45° and 60° of trunk flexion. The subject was instructed to hold each posture for as long as possible until he/she

reached their pain tolerance limit, or for a maximum duration of 600 seconds, whichever occurred sooner. The duration for holding the posture was recorded as the Total Endurance Time (TET).

## RESULTS

Table 1 presents the Total Endurance Time (in seconds) by population percentile for each of the eight age/gender/back strata at five trunk flexion angles. Population percentiles in each horizontal row were estimated from descriptive statistics (mean and standard deviation) using the normal distribution. Minimum and maximum values observed for each stratum are also displayed.

## DISCUSSION

Endurance times for maintaining static trunk flexion postures were measured in a laboratory study and used to produce a table of normative values for a population with chronic back pain and a control group with no back disorders. Endurance times were subsequently estimated for various percentiles of the "healthy" and "back pain" populations. It is likely that conditioning, motivation, distraction, kinesiphobia, and other factors are important variables in postural tolerance. Therefore the data presented may be specific to the circumstances of our testing protocol and subject populations. Although the values in Table 1 were generated from a small sample (10 subjects per stratum), the data clearly demonstrate the significance of both task and personal factors that affect postural tolerance. Additional studies are needed, however, to refine and stabilize the values presented in Table 1. Our study did not include any subjects who were 40-50 years old. Since workers in this age range are vulnerable to back pain, future research should include this group.

Successful management of chronic low back pain lies in timely diagnosis, accurate assessment and appropriate rehabilitation. Clinicians and therapists can use the information in Table 1 to assess the postural tolerance capabilities of new patients and to monitor progress following the institution of therapy. Total Endurance Time is a simple measurement that can be used in any clinic. The only equipment required is a goniometer and a stop-watch.

Prevention of disability can also be facilitated by the information in Table 1. Job designers can use these data to establish work demands that do not exceed postural tolerance capacities of the population. For example, a conservative approach to job design would be to accommodate the most vulnerable worker in Table 1, i.e., the $10^{th}$ percentile person with chronic back pain.

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TABLE OF ENDURANCE TIMES

**Table 1. Total Endurance Time for maintaining static trunk flexion. Table entries show time (secs) for terminating a test due to pain tolerance limit. All tests were truncated at 10 minutes (600 seconds).**

| Trunk Flexion Angle | Health Status, Age, and Gender | | Total Endurance Time (seconds) by population percentile minimum | maximum | 10% | 25% | 50% | 75% | 90% |
|---|---|---|---|---|---|---|---|---|---|
| 0 Degrees | Healthy Backs | Older Females | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| | | Older Males | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| | | Younger Females | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| | | Younger Males | 564 | 600 | 564 | 600 | 600 | 600 | 600 |
| | Chronic Low Back Pain | Older Females | 213 | 600 | 218 | 290 | 591 | 600 | 600 |
| | | Older Males | 303 | 600 | 304 | 326 | 600 | 600 | 600 |
| | | Younger Females | 90 | 600 | 109 | 387 | 600 | 600 | 600 |
| | | Younger Males | 189 | 600 | 189 | 381 | 600 | 600 | 600 |
| 15 Degrees | Healthy Backs | Older Females | 599 | 600 | 599 | 600 | 600 | 600 | 600 |
| | | Older Males | 297 | 600 | 327 | 600 | 600 | 600 | 600 |
| | | Younger Females | 297 | 600 | 297 | 305 | 518 | 600 | 600 |
| | | Younger Males | 20 | 600 | 54 | 411 | 592 | 600 | 600 |
| | Chronic Low Back Pain | Older Females | 130 | 600 | 133 | 162 | 241 | 431 | 600 |
| | | Older Males | 109 | 600 | 111 | 156 | 544 | 600 | 600 |
| | | Younger Females | 56 | 600 | 58 | 106 | 259 | 443 | 600 |
| | | Younger Males | 160 | 600 | 165 | 272 | 362 | 507 | 600 |
| 30 Degrees | Healthy Backs | Older Females | 207 | 600 | 219 | 335 | 588 | 600 | 600 |
| | | Older Males | 211 | 600 | 231 | 430 | 600 | 600 | 600 |
| | | Younger Females | 115 | 600 | 130 | 210 | 249 | 410 | 600 |
| | | Younger Males | 203 | 600 | 204 | 289 | 351 | 419 | 584 |
| | Chronic Low Back Pain | Older Females | 78 | 600 | 81 | 103 | 163 | 254 | 573 |
| | | Older Males | 31 | 600 | 41 | 268 | 375 | 600 | 600 |
| | | Younger Females | 50 | 473 | 51 | 94 | 172 | 311 | 464 |
| | | Younger Males | 0 | 600 | 9 | 115 | 190 | 500 | 600 |
| 45 Degrees | Healthy Backs | Older Females | 157 | 600 | 158 | 233 | 358 | 600 | 600 |
| | | Older Males | 204 | 600 | 204 | 286 | 397 | 600 | 600 |
| | | Younger Females | 89 | 600 | 112 | 250 | 345 | 488 | 600 |
| | | Younger Males | 175 | 505 | 175 | 212 | 240 | 296 | 505 |
| | Chronic Low Back Pain | Older Females | 53 | 600 | 54 | 87 | 187 | 245 | 572 |
| | | Older Males | 90 | 600 | 92 | 107 | 263 | 487 | 600 |
| | | Younger Females | 38 | 295 | 42 | 107 | 145 | 232 | 292 |
| | | Younger Males | 0 | 600 | 7 | 98 | 229 | 389 | 586 |
| 60 Degrees | Healthy Backs | Older Females | 228 | 600 | 231 | 259 | 500 | 600 | 600 |
| | | Older Males | 210 | 600 | 210 | 264 | 471 | 600 | 600 |
| | | Younger Females | 135 | 600 | 139 | 179 | 288 | 446 | 600 |
| | | Younger Males | 170 | 600 | 175 | 237 | 342 | 453 | 597 |
| | Chronic Low Back Pain | Older Females | 53 | 600 | 55 | 85 | 164 | 187 | 560 |
| | | Older Males | 14 | 451 | 17 | 141 | 266 | 389 | 451 |
| | | Younger Females | 56 | 353 | 57 | 66 | 129 | 265 | 340 |
| | | Younger Males | 64 | 403 | 66 | 114 | 191 | 301 | 396 |

# DEVELOPMENT OF A TOOL TO BE USED DURING TELEREHABILITATION EVALUATION & RECOMMENDATION PROCESS

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***Abstract*** – Telerehabilitation shows the promise to be able to improve the access to seating and mobility specialists for people living in rural and remote areas. In order for telerehabilitation to become widely accepted clinical practice, the safety and efficacy must be documented. This is challenging as there is considerable variability among the practices and outcomes of seating and mobility specialists working in-person with consumers. Therefore, we developed a tool suitable for in-person and telerehabilitation assessments by imposing some structure on the process. The tool was developed through a consensus process including clinicians and scientists.

## INTRODUCTION

Many different medical disciplines have tested the feasibility and success of telemedicine in their practices. It is possible to apply the same technology learned in other telemedicine disciplines to the field of rehabilitation (1). Telerehabilitation uses videoconferencing and data acquisition technologies. Telerehabilitation can been used in educational situations between clinicians and rehabilitation experts. It can also be used in rural settings where the delivery of rehabilitation and Assistive Technology (AT) is problematic. The problems of providing Assistive Technology (AT) in rural areas parallel the delivery of health care to rural and remote areas where the proportion of people with chronic illnesses is higher and the means to pay for them is reduced (2). Large distances mean long travel times, increasing costs associated with any service delivery and consuming valuable time specialized professionals could be using to provide services elsewhere. Therefore, individuals living in rural areas that are in need of mobility devices, are facing two major problems: the shortage of specialists in mobility assessment; and the lack of accessibility to specialists for those living in rural areas.

## METHODOLOGICAL ISSUES

Telerehabilitation faces substantial hurdles that include the need for scientific evidence of efficacy, credentialing issues, cost, and reimbursement. Prior to being fully accepted as a clinical tool, telerehabilitation will have to be shown to be effective and safe. Proving the efficacy of a telerehabilitation is a daunting task. It is necessary to prove that the decisions a clinician makes in person are not different than those made during a telerehabilitation evaluation. If two clinicians were identical, one could perform a telerehabilitation evaluation while the other performed and in-person evaluation. If both clinicians agreed it would provide evidence that using teleconferencing technology did not adversely effect the clinical decision making process. In reality clinicians frequently differ in their approach to the same patient, even under identical circumstances.

Obtaining an accurate outcome measure of functional status depends upon the ability to administer the same assessment procedures in both the rehabilitation and the home setting. Data collection tools need be developed to assist in coherent assessment procedures in both settings.

## FORM DESIGN

Two data collection forms that have been created for a telerehabilitation study being conducted at the Human Engineering Research Laboratories affiliated with the University of Pittsburgh and the VA Pittsburgh Healthcare System. Designed to be an experimental crossover study, the investigations primary goal is to establish a scientific basis for the reliable use and limits of telerehabilitation during mobility assessments. The data collection forms were designed to address the need for outcome documentation at the evaluation and the prescription level during the telerehabilitation evaluation. Clinicians and scientists with extensive experience in seating and mobility contributed to the format and the content to the data collection forms.

The evaluation and the prescription data forms are comprehensive questionnaires, which are designed in a decision tree format. The evaluation form will guide the clinician through the data collection on functional status, a comprehensive mat-evaluation, manual muscle testing, range of motion, and seating measurements. The prescription form will guide the clinician through the mobility recommendation process incorporating the evaluation findings. A scale for the clinician to indicate their level of confidence in their decision accompanies each question.

These forms will be used in a protocol consisting of an interview, to establish the need, the appropriateness and the goal for assistive technology intervention; and a mat evaluation, for baseline information on physical/mobility information. Four clinicians evaluate each subject, for a total of 20 subjects or 80 evaluations, one time only either by telerehabilitation (TR) or in-person (IP). As part of this process, a clinical assessment form and an evaluation checklist are used to record information on the individual and their mobility status.

*Test Hypotheses*

For all hypotheses, the kappa statistic will determine the level of agreement. The two methods will be considered in agreement if Kappa is greater than 90%.

1) Results of the IP assessment with regard to history and physical examination will be in agreement of the results of the TR assessment.
2) Results of IP prescription from with regard to type of mobility including seating system needed (manual, attendant propelled, power, scooter) will be in agreement of the results of the TR prescription form.

To date, the pre-study phase of mock- evaluations conducted to test TR video set-up and to evaluate the data forms by all four clinicians have been concluded. Data collection forms have been updated and recruitment of subjects and data collection is in progress.

*Data collection*

A database has been designed to collect discrete and ordinal data elements. Discrete data will be collected upon screening (yes/no for full evaluation, wheelchair characteristics, etc.). Statistical analysis will include levels of agreement or consistency between the two methods of assessment that will be represented by proportions. Also, a chi square test of association will be used to test whether the amount of agreement is significantly different than chance.

## DISCUSSION

Clinicians specializing in seating and mobility tend to develop personal techniques for performing evaluations and for discerning the appropriate recommendation. However, the lack of a standardized protocol creates two challenges: (1) it is difficult to estimate the outcomes of the recommendation *apriori*; and it is difficult to transfer the procedures from one clinic to another or to accommodate a change in the medium (e.g., introduce telerehabilitation). In order to assess telerehabilitation, we developed a process to impose some structure on the in-person seating and mobility assessment. The process was designed to be suitable for in-person and telerehabilitation assessments. Standardized protocols have been used in other clinical settings (e.g., electromyography) where variations in the techniques can alter the outcomes. At this stage in our study, we are examining agreement at a gross level. Future studies will be designed to examine the limitations of telerehabilitation for seating and mobility assessments. Many questions remain unanswered regarding telerehabilitation, but some of the pressing issues address what are the limits of the technology (POTS, ISDN) and when is a consult needed (i.e., live or virtual).

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RELIABILITY OF A NEWLY DEVELOPED ACTIVITY MEASURE FOR WHEELCHAIR USERS

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## ABSTRACT

The Activity Measure is a newly developed questionnaire that assesses wheelchair users' level of independence in basic and instrumental activities of daily living. The goal of the Activity Measure is to provide a stable and efficient method of comparing an individual's function before and after an intervention, for example, the introduction of assistive technology such as a service animal. The purpose of this pilot study was to test reliability of the Activity Measure. In this study, raters administered the Activity Measure to six subjects on three different occasions over a three-week period. Reliability, consisting of both intra and interrater reliability, was evaluated. Both intra and interrater reliability were excellent.

## BACKGROUND

A 1994 study by the National Center for Health Statistics found an estimated 7.4 million persons in the U.S. household population use assistive technology for mobility, and of those individuals, 1.6 million use wheelchairs [1]. This is an 82.6 percent increase in U.S. wheelchair usage since 1980. Reasons for growth in the use of mobility devices include an increase in the number of Americans over the age of 65 years and the greater rate of survival of previously fatal injuries or conditions.

The Americans with Disabilities Act of 1990 and the Assistive Technology Act of 1998 (PL 105-394) recognized that improvements in the quality of life for individuals with disabilities could be accomplished by enhancing accessibility and the individuals' ability to perform activities of daily living in their routine environments [2], [3]. Evaluation of ability to complete basic activities of daily living or BADL (self-care tasks) and instrumental activities of daily living or IADL (environmental management and accessibility) is therefore vital to understanding the needs of individuals with mobility impairments. Furthermore, documentation of wheelchair users' need for attendant care, assistive technology, and/or environmental accommodation can assist with funding justification, identification of opportunities to improve independent function, and advancements in discharge planning. Likewise, understanding the needs of wheelchair users can support research and development of assistive technology specific to this population.

Current wheelchair measurement tools evaluate seating prescription, mobility, decubitus ulcer risk, shoulder injury, and safety during transportation [4], [5], and [6]. These tools address proper fit and safety with wheelchair use. However, they do not identify issues characteristic to completion of activities of daily living for individuals who use wheelchairs and their unique needs. Since few measures address this area of ADL-specific needs of wheelchair users, the Activity Measure questionnaire was developed.

The Activity Measure is a questionnaire that asks subjects to rate their level of independence in completing tasks in ten domains: transfers, bathing and grooming, dressing, bed mobility, positioning, meal/food preparation, wheelchair mobility, housekeeping, exercising, and leisure activities. If the need for assistance in a particular domain is indicated, the rater asks more specific questions about tasks within the domain to determine more precisely the level of independence. Levels of independence include completely independent, independent with an assistive device (i.e., a service animal, reacher, etc.), human assistance, or completely dependent.

This pilot study was conducted to determine the reliability of the Activity Measure. Reliability, a desirable psychometric characteristic, is the degree to which the same results are obtained on two or more occasions with the same sample. Reliability is expressed as being both intrarater and interrater reliability. Intrarater reliability measures one rater's reliability by comparing that rater's scores on the same subject across subsequent assessments. Intrarater reliability precedes establishment of interrater reliability. Interrater reliability is the degree to which two or more raters obtain the same results when administering the questionnaire on the same sample.

## METHOD

### Research Question

What is the reliability of the Activity Measure questionnaire?

### Study

Subject recruitment consisted of phone calls to individuals who had participated in previous research studies. Subjects were individuals who used wheelchairs as their primary means of mobility. The subjects of the study were distributed as follows: of six subjects total, five were men, median age was 45 years, with a range of 31 to 66 years, and median years of disability was 20 years with a range of 6 to 47 years. Subject distribution across diagnostic categories was: one individual with multiple sclerosis, one individual with had cerebral palsy, three individuals with spinal cord injuries, and one individual with spinal muscular atrophy. Other sample characteristics were: one was a veteran of the U.S. armed forces and five were Caucasian.

Subjects were randomly assigned to different order of raters to eliminate order effects. The raters administered the Activity Measure to six subjects on three different occasions over a three-week period. Time intervals for second and third interviews ranged from four to seven days to eliminate practice effects inherent in repeated measures testing.

### Design of Questionnaire

The Activity Measure is structured with eleven domains of BADL and IADL including ambulation, bathing, grooming, dressing, bed mobility, bed positioning, meal/food preparation, indoor housekeeping, outdoor housekeeping, exercising, and leisure activities. If assistance was required for a domain, the rater asked additional questions regarding tasks specific to that domain.

### Analytic Methods

The Kappa statistic was used to interpret the data obtained, as it is a measure of reproducibility for categorical data. Both intrarater (within-rater) and interrater (between-rater) reliability Kappa's were formulated using SPSS®. Kappa statistics of greater than 0.75 are considered to signify excellent reproducibility, while Kappa's between 0.4 and 0.75 denote good reproducibility. At this time, only questions asking subjects if assistance was required in the domains were included in the analysis.

## RESULTS

Intrarater reliability was found to have excellent reproducibility as both raters had Kappa's for all domains of >0.9. Interrater reliability was found to have excellent reproducibility in 60% of the domains including: ambulation, dressing, bed positioning, meal preparation, household chores, and exercise. Good reproducibility was achieved in 30% of the domains including: bathing and grooming, bed mobility, and leisure activities. These results are preliminary and require additional investigation.

## DISCUSSION

Reliability of the Activity Measure was evaluated by comparing data obtained by administering the questionnaire to six subjects three times over a three-week period. The subjects were individuals who used mobility devices as their primary means of mobility. Study limitations resulted from time and cost constraints and included small sample size, an unequal distribution between gender, and limited diagnostic categories within the sample. Validity, or the extent to which a test measures what it is suppose to measure, was not evaluated.

National policies have recognized that assistive technology and environmental accessibility have had a positive impact on the lives of individuals with disabilities by improving their independence in basic and instrumental activities of daily living. As a result, assessment tools that can document this impact are needed to promote funding and document improvements in service delivery. Though it requires additional research and testing, the Activity Measure may indeed provide a reliable means to document intervention by clinicians and assistive technology practitioners.

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# THE DEVELOPMENT OF VALIDITY AND TEST-RETEST RELIABILITY FOR MEASURING OF THE EFFECT OF WHEELCHAIRNET ON WHEELCHAIR DECISION-MAKING BY CONSUMERS

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**Abstract**

WheelchairNet, a WWW resource developed as an education and dissemination tool by the Rehabilitation Engineering Research Center on Wheeled Mobility, contains information useful to consumers preparing for wheelchair selection in partnership with providers and suppliers. Questionnaires were developed to measure the effect of WheelchairNet on participant's goals, health locus of control, knowledge, and expectations about mobility device attributes and their availability. Content validity of 10 categories of knowledge was established through the expert opinion of 12 OTs and PTs specialized in seating and mobility. Test-retest reliability was estimated using a weighted kappa as a chance-corrected measure of exact agreement. A mean K of .75 was obtained on 8 of 10 items in the "Self-assessment of wheeled mobility knowledge" and .62 on 20 items in the "My next wheelchair" indicating substantial test-retest agreement.

**Background**

To measure the effect of WheelchairNet on consumer decision-making, data collection tools were needed to establish a baseline level of goals, knowledge, and expectations for comparison with levels after exposure to either experimental or control conditions. This study, to be conducted entirely via the WWW, will test the hypothesis that motivated consumers exposed to WheelchairNet will improve their knowledge and readiness for a more active role in wheelchair selection and decision-making. No tools for measuring mobility device-related knowledge or readiness to participate in wheelchair decision-making were found. A review of applied decision research led to the working hypothesis that human decisions are heavily influenced by the strength of goals and the knowledge of and availability of options [1, 2]. Concepts that represent the knowledge areas in a comprehensive wheelchair and seating assessment were identified [3, 4]. A consumer-based criteria for evaluation of assistive devices [5] was used along with current areas of interest in wheelchair research to develop items for the wheelchair expectations.

**Research Questions**

Questionnaire development was guided by the following: What are the areas of wheelchair knowledge considered important by experienced seating and mobility clinicians? What characteristics of mobility devices are important to consumers? Will the developed questionnaires provide sufficient stability to measure change?

**Method**

Validity

Of 23 seating and mobility specialists who were invited by email to participate in establishing content validity, 12 (5 OTs, 7 PTs) responded. The expert panel had an average of 15 years of experience and 9 were ATP certified. Ten statements representing components of a comprehensive seating and mobility assessment were written following a review of the literature. The panels of experts were asked to rate their agreement about the importance of consumers who use wheelchairs possessing knowledge on these topics. The experts used a 10-point scale, ranging from 1-Hardly ever important to 10-Always important. For each of the 10 items, mean agreement scores ranged from 7.5 to 9.0 with a median of 8.3. The items with the highest variance were examined for systematic variation. There was a positive correlation of .75 ($p=.01$) between ATP certification and high total agreement scores. Changes in item wording were made in response to raters' suggestions. The item about reimbursement was deleted because of ambiguity and knowledge of wheelchair type was added. The 10 items of the "Self-assessment of wheeled mobility knowledge" are rated on a 5-point ordinal scale ranging from "poor" to "excellent."

"My next wheelchair," was developed to measure consumer expectations about characteristics of their next wheelchair. Five of the items were taken directly from consumer-generated criteria for evaluation of assistive devices [5]. The characteristics of wheelchairs ranked one and two, effectiveness and operability, were used to develop additional items. Effectiveness and operability are more easily measured in specific features of wheelchair technology. For example, effectiveness is manifested in ability to travel on uneven surfaces or maneuver in tight spaces, and operability in using energy efficiently or in having options in location of controls. Other items were chosen because they are the current focus of RERC research, e.g., securability in motor vehicles, cushion choices, and prevention of overuse injuries. This 20-item questionnaire is rated on a 5-point ordinal scale ranging from "not at all important" to "very important."

A third questionnaire, "My life goals," used the three domains of human activity of the Canadian Occupational Performance Measure [6]. Participants were asked to write a personal goal for productivity, self-care, leisure, and mobility and then to rate their likelihood of accomplishing each goal. This questionnaire will determine the relationship between strength and type of goals and readiness to participate in wheelchair selection. This questionnaire will be analyzed with qualitative software, NUD*IST [7], to index, code and theorize about themes imbedded in the data.

Reliability

Ten individuals participated in a pilot study to assess the test-retest reliability of the questionnaires developed for this study. The seven men and three women were community living adults with non-progressive impairments who use the Internet for email and the WWW and who use wheelchairs as their primary means of mobility. Measures of reliability are best achieved when the subject pool has a high degree of variability. Efforts were made to recruit persons using both manual and power chairs and with varying lengths of wheelchair use. All 10 participants had at least some college education and seven had graduate degrees. They used defined procedures to complete the questionnaires and returned to the study website and retook the questionnaires within four days

The kappa statistic, $\kappa$, a chance-corrected measure of agreement was used to estimate stability. Kappa looks at the proportion of observed agreements and considers the proportion of those agreements expected by chance. A weighted kappa, created by squaring the deviation of time one from time two, penalizes retest responses further than one category apart (e.g., time 1= 3; time 2= 5) [8]. Questionnaire items appearing stable under this more strict criterion would convey greater confidence when used to measure intervention effects on the posttest scores. Test and retest scores for 30 items were analyzed using an MS Excel spreadsheet with cells containing formulas for the weighted agreement matrix [$\kappa=(t_1-t_2)^2$] to determine chance corrected agreement. Since errors were made in coding the html form used to collect the retest results, data were lost for two of ten items. The estimate of stability for the 8 remaining knowledge items is probably a fair estimator of the stability of the two missing items. The mean kappa statistic for the "Self-assessment of wheeled mobility knowledge" is .75 and for "My next wheelchair" is .62. The results follow:

| Self Assess W/C Knowledge items | κ | My Next W/C items | κ | My Next W/C items | κ |
|---|---|---|---|---|---|
| 1 - Pressure Relief | .92 | 1 - Ease of use | .26 | 11 - Energy efficiency | .59 |
| 2 - Seating Comfort | -- | 2 - Dependability | .00 | 12 - Footrest options | .40 |
| 3 - Riding safely in motor vehicle | -- | 3 - Durability | .00 | 13 - Handling ease for others | .83 |
| 4 - Prevention of overuse injuries | .87 | 4 - Adjustability | .67 | 14 - Controls location | .92 |
| 5 - WC features & longterm health | .78 | 5 - Appearance | .44 | 15 - Maneuver tight spaces | .57 |
| 6 - Relationship WC & activities | .33 | 6 - Back support | .92 | 16 - Non-paved surface | .82 |
| 7 - Methods paying for WC | .80 | 7 - Compatability | .78 | 17 - Securability | .96 |
| 8 - OT/PT contribution to eval/selec | .66 | 8 - Cushion choices | .94 | 18 - Tire choice | .52 |
| 9 - Client-centered assessment | .93 | 9 - Prevent overuse | .48 | 19 - Travel distance | .57 |
| 10 - How to create WC accessibility | .73 | 10 - Uneven surface | .73 | 20 - Physical comfort | .92 |

## Discussion

The mean estimated measures of agreement for these questionnaires are considered "substantial agreement"[8]. Kappas <.40 were obtained for one item in the "Self-assessment of wheeled mobility knowledge" and six items for "My next wheelchair." Weighted Kappa, assuming chance is responsible, penalizes high levels of agreement with κ=.00. For items such as the relationship between wheelchair features and life activities, causes of overuse injuries or the contribution of footrests to seated posture low κ scores may indicate lower knowledge levels on these topics. The scores, on average, offer sufficient reliability to allow the developed questionnaires to be used in future research for measuring the impact of interventions on consumer knowledge and expectations.

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# APPLICATION OF THE CANADIAN OCCUPATIONAL PERFORMANCE MEASURE TO EVALUATE AN AUGMENTATIVE COMMUNICATION INTERVENTION PROGRAM FOR DEAF ADOSLESCENTS

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## ABSTRACT
The objective of this paper is to demonstrate how the Canadian Occupational Performance Measure (COPM) could be effectively used to evaluate an augmentative communication intervention program for a group of deaf adolescent students possessing limited ability to communicate with hearing community members, and an inability to read and write. This paper adds to the body of knowledge that demonstrates how existing tools can be expanded or narrowed in scope, or modified in some fashion, to be used in the evaluation of a wide range of assistive technology (AT) intervention outcomes.

## BACKGROUND
There is data to indicate that, on average, 30% of 18-year old deaf students leaving high school are functionally illiterate (1). These students may have adequate signing skills to function within the school environment or within the Deaf community, but possess reading and writing skill below the level necessary to function independently in a hearing society.

The deaf are proud of their culture and their language (American Sign Language). Historically, augmentative and alternative communication (AAC) is not widely accepted by "Deaf Culture", and is viewed as a method to be used by people who have something "wrong" with them. However, AAC can provide the link to a hearing society that will lead to an increased probability of independent community interaction, and success in a vocational setting, for members of the deaf population who are unable to read or write.

The Individuals with Disabilities Education Act (2) mandates that the educational system provide transition services that focus on independent living and post-graduate employment skills. Toward that end, the intervention program being evaluated involves the provision of a picture symbol communication book to aid deaf adolescents in their interactions with hearing community members. It is hypothesized that this communication aid will increase the students' ability to function independently within the community in terms of fulfilling his wants and needs when performing community transactions, e.g. purchasing needed items and improving communication in vocational settings.

## OBJECTIVE
In the field of augmentative communication, the complexity of the systems and the intricacies of the communicative process have played a large part in the challenge to develop studies that lead to development of general outcomes tools (3). This paper adds to the body of knowledge that demonstrates how existing tools can be expanded or narrowed in scope, or modified in some fashion, to be used in the evaluation of a wide range of assistive technology intervention outcomes. The objective of this paper is to describe how the Canadian Occupational Performance Measure

could be used to evaluate the effectiveness and worth of an augmentative communication intervention program at a public school for the deaf.

## METHOD

### Target Population

The project would involve deaf adolescents, ranging in age from 12 to 21, attending a public school for the deaf. Students will be selected who possess a level of sign language skill which allows them to communicate effectively with other individuals who use sign language, but who do not have the ability to make their wants or needs known to the hearing community through written language. According to standard developmental stages, students of this age would experience an increasing need and opportunity for independent community involvement and interaction.

### Tools

The COPM is designed to measure a person's self-perception, over time, of his occupational performance, and satisfaction with his performance, in the areas of *self-care*, *productivity* and *leisure*. Through a semi-structured interview the person identifies significant issues in daily activities, within the previous 3 categories, that are causing difficulty (4). This process assists the person to gain insight into his abilities and difficulties and, together with the intervention staff, to develop a customized intervention plan focused on the amelioration of the specific problems and needs that have been identified

The COPM is a good match for use with deaf students who are candidates for a picture symbol communication book. The wording/signing of the interview questions can be modified to make them understandable to each student on an individual basis without compromising the integrity of the assessment. In using the COPM for this application, the focus of the three main categories would be narrowed down during the semi-structured interview to include only activities involving community interaction. Under the category of *self-care*, tasks related to community management (e.g., transportation, shopping, finances) would be targeted. The category of *productivity* would focus upon such issues as finding or keeping a paid or unpaid vocational position. Entertainment events or travel would be discussed under the *leisure* category. In addition, the COPM is a good match for evaluation of effectiveness and worth of this AAC intervention program. This tool measures occupational (functional) performance and satisfaction, both of which are dependent variables of this study. The pre-intervention interview determines a baseline functional performance measurement and an initial numeric indication of the student's satisfaction with his functional performance. This tool allows, and even prefers, that both the student and the intervention team collaborate on intervention goals based upon the initial results from the assessment, thus increasing the student's stake in a successful outcome and allowing the student to take a more active, problem-solving role in the intervention experience (5).

As an addendum to the post-interview process, several questions are suggested which are designed to elicit information not captured by the COPM, and which would be useful in improvement of the intervention process: Did you feel prepared to use your communication aid? Did you feel comfortable using your communication aid? Did you have adequate symbols in your communication book? Can you think of some ways that we can improve the communication aid?

APPLICATION OF THE COPM

Intervention

A customized set of picture symbols will be produced based upon the problem areas that were identified. The student will generate the required picture symbols on a computer using Mayer-Johnson "Boardmaker" software and place the picture symbols into a pocket-sized book. The student will use the book while performing community-based activities to communicate wants and needs to hearing individuals. After a 3- month period, each student will be re-assessed using the COPM. The student will rate his functional performance and his satisfaction with his performance in the activities originally identified as problem areas. The new ratings are then compared with the original ratings to calculate the change in scores over time. This process allows the student and intervention team to have numeric estimates of perceived changes that have occurred as a result of the intervention (4). This method would not only evaluate the effectiveness of the program, but, utilized as a formative evaluation, would serve to gather information needed to improve the program.

DISCUSSION

This scenario demonstrates how an existing AT outcomes tool can be appropriately matched to clinical evaluation needs by examining the following three factors: (a) indicators or qualities that the tool measures vs. program indicators or qualities one desires to measure; (b) appropriateness of the tool's administration method for the disability population associated with the program evaluation; and (c) utility of the tool in its original format and the relative ability to modify the tool in order to meet the evaluation needs of the project without compromising the integrity of the tool.

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# Seating and Mobility
# (Topic 8)

# DESIGN OF AN OBLIQUE ANGLED SUSPENSION FORK FOR WHEELCHAIRS

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## ABSTRACT

Wheelchair casters are subject to high impacts that directly affect wheelchair comfort and durability. Shock absorbing casters have been developed but the alignment of the shock-absorbing object has not been optimized since they are oriented either horizontally or vertically. In the design of the oblique angled suspension fork, the shock absorber is tangential to the curve at which the top and bottom parts rotate towards each other. The caster's effectiveness in absorbing shock was then tested against a caster without suspension by taking acceleration measurements while driving the casters over a mat with rumble strips and a door threshold in a wheelchair. Overall, the casters showed some improvement over conventional casters.

## BACKGROUND

Wheelchair ride and comfort is important in avoiding secondary injuries due to extended wheelchair use. These secondary injuries can either be musculoskeletal injuries or neurological injuries [1]. When traveling over obstacles in a manual wheelchair, the resulting forces are transmitted through the casters and the wheels, through the frame, through the seat cushion, and to the body of the wheelchair user [4]. Vibration at the first human resonance frequency can eventually lead to herniated discs, spinal deformities, and chronic low back pain [2]. Vibration and impact forces can also be a factor in reducing fatigue life in wheelchairs, eventually leading to failure in the frame, at the welded joints, and in the casters, which would jeopardize the safety of the wheelchair. In fact, frame failures top the list of engineering factors in wheelchairs in a report to the FDA [6]. To compensate for high and repeated forces, the wheelchair industry has attempted to dampen the shock from these forces in casters. Virtually ever wheelchair caster has either a pneumatic wheel, a foam filled wheel, or a polyurethane wheel to help in absorb some shock. But, this can only provide a small shock absorbing effect, which has inspired other attempts in absorbing shock at the fork. Suspension caster forks are a way that manufacturers have tried to absorb shock. The idea behind these caster forks is to insert a shock absorber into the design of the caster fork that will allow some flexibility. Frog-Legs is such a suspension caster (Vinton, Iowa). It has a shock absorber that is oriented vertically and it is successful in absorbing shock vertically. Other attempts in suspension casters, such as Invacare Corporation (Elyria, Ohio), have oriented the shock absorber in a horizontal direction and they are capable of absorbing shock in the horizontal direction.

## RATIONALE AND STATEMENT OF PROBLEM

Vertical or horizontal orientation of shock absorbing material is not optimal in reducing shock. Orient shock-absorbing material at an angle that will absorb energy in horizontal and vertical directions. The principal behind the new design is to have the shock absorber tangential to the axis of rotation.

## DEVICE DESIGN

In designing the oblique angled suspension caster forks (OASCF), an analysis of current commercial designs was completed. Figure 1 shows a vertically oriented polyurethane elastomer shock-absorbing fork. A suspension caster fork with a vertically oriented shock absorber is shown in Figure 1. When a typical obstacle is run over, such as in Figure 1, the reaction force creates a bending moment on the elastomer because of the caster's geometry. The end result is that a nonoptimal stress distribution is found through the elastomer as shown in Figure 2. Ideally, the elastomer should be in full compression to dissipate the shock as efficiently as possible. A study done by VanSickle et al. on road loads acting on wheelchairs was done using the ANSI/RESNA fatigue tests of the curb drop and the double drum along with "real-world" driving [3]. In the vertical direction, casters must experience impact forces that are 937 Newtons and consistent forces up to 625 Newtons [3]. Horizontally from the front to the back of a wheelchair, casters may be subject to frequent forces at around 437 Newtons [3] on the double drum and impact forces of 217 Newtons on the curb drop [3]. If such high forces are found horizontally and vertically in the casters then to prevent that shock from transmitting to the wheelchair user, the suspension casters must be able to effectively dissipate shock in both the vertical and horizontal directions.

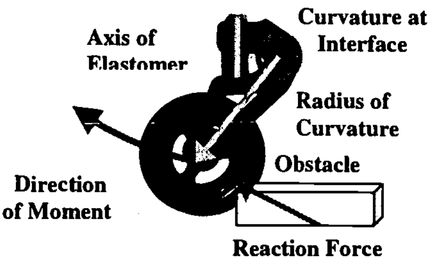


**Figure 1: Frog-Legs Suspension Caster Forks**

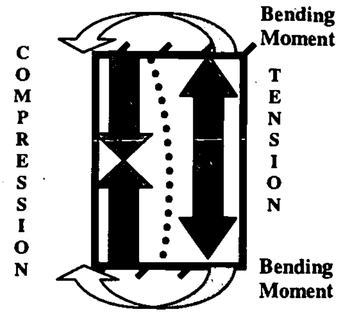


**Figure 2: Stresses of Elastomer in Frog-Legs Casters**

When an obstacle hits the wheel as in Figure 3, the caster rotates about the bolt that locks the two pieces together and along the curvature in the interface of the two pieces, creating a moment about this point. The elastomer is oriented tangential to the curvature of the interface and perpendicular to the path of rotation of the swing-arm about the pivot. Using this geometry, the reaction force creates only an axial force on the elastomer. The elastomer is then in compression as in Figure 4 and can dissipate the shock efficiently.

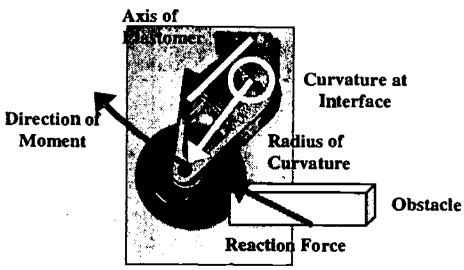


**Figure 3: Oblique Angled Suspension Caster Forks**

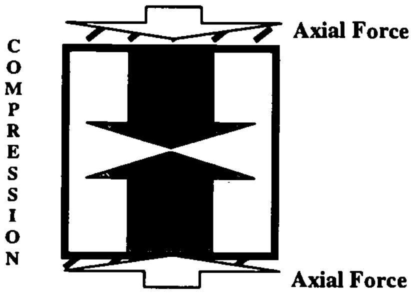


**Figure 4: Stresses of Elastomer in New Casters**

## DEVELOPMENT

The caster fork was developed for an ultra lightweight wheelchair and is more compact than most caster forks as seen in Figures 5 and 6. The fork was designed to use 3" (76.2 mm) diameter, 1" (25.4 mm) wide wheels or about the size of an average inline skate wheel. The body of the new caster forks is machined from aluminum alloy 6016-T6. This alloy was chosen because it is has high strength, a high corrosion resistance, is easily machinable, and is often used in vehicle parts. The choice of the elastomer's stiffness is dependent on geometry and load on the elastomer. By using a form of the stress-strain relationship in Equation 1, the proper stiffness of the elastomer can be found.

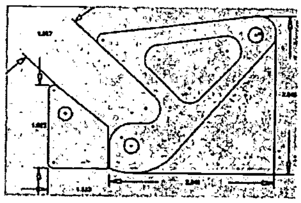

**Figure 5: CAD drawing of OASCF**

In this equation, $L_i$ is initial length of elastomer, $A_c$ is the cross-sectional area of elastomer, and $\Delta L$ is the change of length of the elastomer after the load has been applied. The load on the elastomer ($F_e$) can be found, as in Equation 2, by multiplying the impact force ($F_w$) on the wheel by the ratio of the moment arm between the axis of the elastomer and the point of rotation ($R_{ae}$) and distance of the radius of curvature ($R_{roc}$).

$$E = (F_e * L_i)/(A_c * \Delta L)$$

**Equation 1**: Elastomer Stiffness from stress-strain relationship

$$F_e = F_w * (R_{roc}/R_{ae})$$

**Equation 2**: Load on Elastomer from definition of moment

For the caster seen in Figure 6, a polyurethane elastomer with a hardness of 80A and Young's modulus of 20 MPa. "A" is a durameter scale that is used to measure the hardness of rubbers and polyurethanes. Shore A ranges from 10 to 95 and the higher number represents a harder material. In general, polyurethane is a linear elastic material when exposed compression loads [5]. Polyurethane has greater energy absorption than similar rubbers and plastics [5].

## EVALUATION

To evaluate the effectiveness of the OASCF's on absorbing shock they were contrasted against a standard caster fork on the same wheelchair. The test consisted of driving a wheelchair with the OASCF's over a mat with ¼" (6.4 mm) rumble strips and then over a ½" (12.7 mm) door threshold [3]. A multi-axial accelerometer (ADXL05EM-3, Analog Devices, City, State) was mounted on the footplate to measure the amount of shock that experienced by the foot because it is where shock from the casters is transmitted first to the body as in Figure 5. The accelerometer data were collected at a rate of 200 Hz. The test-pilot, a 55 kilogram experienced wheelchair user, was asked if he noticed any change between the two casters on the course. The OASCF's were successful in reducing the acceleration that is experienced in driving over a door threshold or rumble strips. The peak-to-peak acceleration was analyzed in the door threshold because of the small amount of time that is expired between the initial contact and the descent of the casters on the threshold. There was a modest decrease (17.95 +/- 1.73 $m/s^2$ for the OASCF compared to 19.58 +/- 3.08 $m/s^2$, N=5) of the peak-to-peak acceleration in the OASCF and the driver felt a dampening effect of the new caster forks. . The vibrational dose value (VDV) is the amount of energy that the footrest experienced while traveling over the rumble strips, see Equation (3) where a(t) is the acceleration as a function of time [7]. This measurement also showed a modest decrease of acceleration in the OASCF (111.12 +/- 3.06 over 2.39 +/- 0.04 s for the OASCF compared to 128.13 +/- 8.03 over 2.41 +/- 0.06 s, N=5).

$$VDV = [\int a^4(t)dt]^{1/4}$$ **Equation 3**: Vibration Dose Value

## DISCUSSION

The new casters showed improvement over conventional casters. The OASCF's are successful in absorbing shock as determined by the data and the feedback of the subject. Still, the dampening of the elastomer tested does not appear to be optimal for this subject. To improve the dampening of the elastomer, the elastomer in the caster probably needs to be softer with a hardness of around 70A or 60A instead of 80A. Future work on the casters could lead to further improvements. The proper stiffness of the elastomer should be looked at closer so its stiffness is selected for the person's mass and wheelchair set-up. Possibly a variable stiffness elastomer could be developed to be used in the forks. This elastomer could be easily adjusted according to the weight or obstacles the casters are exposed to. A comparison between the OASCF's and commercial suspension caster forks could improve designs under different loading conditions.

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# ACTIVITIES OF DAILY LIVING IN NON-WESTERN CULTURES: RANGE OF MOTION REQUIREMENTS FOR HIP AND KNEE JOINTS

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## ABSTRACT

The purpose of this exploratory study was to investigate the functional range of motion (ROM) requirements of non-Western populations in respect to hip and knee joints. A review of the literature and discussions with key informants indicated that in Asia and the Middle East many activities of daily living (ADLs) are performed while squatting, kneeling, or sitting cross-legged. These positions demand a greater ROM than that typically required in Western populations. In conclusion, this study stresses the importance of culture and function in the design and use of assistive technologies. This paper is of interest to therapists, designers, and those working in the area of seating, mobility and orthotics.

## BACKGROUND

When designing new assistive technologies cultural differences must be considered; a culturally appropriate design has a greater chance of being successful in meeting an individual's needs.

## RESEARCH QUESTION

The purpose of this study was to identify how ADLs are performed in Asia, and more importantly, the ROM required.

## METHOD

An extensive review of the literature was conducted. To ensure local sources of information were not overlooked *key informants* in various countries and professions (orthopedics, rehabilitation, orthotics, prosthetics) were consulted. Several field-visits to India, Hong Kong, and the Middle East were made for observational purposes and to validate findings.

## RESULTS

### *Positions*

Culture has a significant impact on how ADLs are performed (1). In many parts of Asia *floor-sitting* positions such as squatting, kneeling, or sitting cross-legged, are used for ADLs (2),(3),(4),(5). Research thus far on sitting is culturally biased, in that the focus is on chair sitting postures and behaviors as found in Western cultures (2),(3),(4). This bias is interesting, as the greater percentage of humankind habitually floor-sits at work or rest (4). Floor-sitting positions may also be used by individuals in Western society and are therefore not exclusive to the East. The reader must be cautious in making generalizations about populations as differences exist within countries and cultures, and between individuals.

### *Squatting*

*Squatting* is best defined as a position where the plantar surface of at least one foot is in contact with the ground, and the legs are extremely flexed bringing the body down over the feet/foot. Toileting is likely the most important activity performed in squatting. Much of the world's population i.e., Japan (6),(7), China (8), India (9) and the Middle East (1) use an Eastern style toilet (bowl embedded in the floor) whereby a squat position is used for voiding (10). Bathing may also demand a squat position to pour water over the body from a bucket or tap (1),(9). In villages, toilet and bathing facilities are often limited; people squat to toilet in fields, or to bathe in a river/lake (9),(10),(11). Squatting is also used for household chores, socializing, working, and religious acts (5),(9),(12).

It is important to be aware of differences in the performance of ADLs between countries, but also within a given country. Studies conducted in Pakistan found that people in a rural setting tended to use squat positions for activities (9),(10),(11), more than the affluent, and often more urban population.

The work by Blair (13) conducted in the Maldives Islands is perhaps the most recent and comprehensive study done on squatting. The findings indicate that the ability to squat amongst a population which regularly squats is due to increased joint flexibility in the joints used in squatting as well as joints not used in squatting. The increased ability to squat is more likely due to lifestyle than a genetic predisposition.

***Kneeling***

*Kneeling* is best defined as a position where at least one knee is in contact with the environment (i.e., ground) and the body and weight are supported predominantly through the knee/s. In Japan kneeling is commonly used for eating, socializing, religious or traditional ceremonies (2),(6),(7),(14). Kneeling is also common in Islamic countries. A person following Islamic practices may pray from the age of 7-years, 5 times per day (1). In Pakistan those who pray may flex their knees as often as 70 times per day (11). A radiographic study of the kinematics of deep knee flexion in the prayer positions in 5 healthy Saudi Arabian men identified that the there are two primary motions; a) kneeling with knees fully flexed (150° - 165°) and torso upright and, b) moving from a kneeling to bowing position (head touching the ground) with the knees eventually decreasing flexion to 90° (15).

***Cross-Legged***

The *cross-legged* position may be used for resting, socializing, eating, work, leisure or spiritual activities (5),(7),(9),(12),(16). Although this position is commonly observed in Asia, virtually no information was located.

**DISCUSSION**

Different professions have studied ROM in floor-sitting positions in varying degrees of detail. Table 1 summarises the opinions of 9 authors from around the globe regarding the lower extremity ROM necessary to floor-sit. There is a significant spread in ROM recommended and gaps in information available. It is interesting to compare these results with those forwarded as the ROM required by Western populations.

Johnston and Smidt (17) measured the ROM necessary at the hip for different ADLs as performed by a Western population. They deduced that the ideal results of hip arthroplasty (i.e, functional movement) would be, "120° flexion, 20° abduction, and 20° external rotation" (29, p. 215). A similar study measuring knee flexion proposed an individual required 90° to descend stairs, 93° to rise from a chair, and 117° to lift an object (18). When comparing the results in Table 1 with these standards it is apparent that the floor-sitting positions demand greater ROM than that proposed for Western populations. The ROM suggested for a Western population would not allow many people in Asia and Middle Eastern cultures to continue with their usual lifestyle.

**Table 1: Summary of Range of Motion (in degrees) Required for Three Sitting Positions**
Sourced from (5),(7),(8),(12),(13),(14),(15),(16),(19)

| Movement | Full Squat | Kneel | Cross-Legged |
|---|---|---|---|
| Hip Flexion | 130 - full** | * | 90 - 100 |
| Hip Extension | N/A | N/A | N/A |
| Hip External Rotation | 5 - 36 | * | 35 – 60 |
| Hip Internal Rotation | * | * | N/A |
| Hip Abduction | 10 - 30 | * | 40 – 45 |
| Hip Adduction | * | * | N/A |
| Knee Flexion | 111 - 165 or full** | 111 - 165 or full** | 111 -165 or full** |

* no data located
** full range of motion varies with the individual

## A.D.L. IN NON-WESTERN CULTURES: R.O.M. REQUIREMENTS

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# TECHNIQUES OF DATA COLLECTION FROM TWO SMART$^{WHEELS}$

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## ABSTRACT

The SMART$^{Wheel}$ is a device developed by Human Engineering Research Laboratories, which has a digital force and moment sensing pushrim on the wheel. By processing the data collected from SMART$^{Wheels}$, we could calculate the forces on the wrists and shoulders of manual wheelchair during propulsion. In this paper we introduced the techniques of data collection from two SMART$^{Wheels}$ simultaneously. The data from two SMART$^{Wheels}$ could be accurately recorded through two R-S232 serial ports using one computer. The baud rate of each port is reach at 38400 bits/s. While recording data, the waveforms of pushrim forces Fx, Fy and Fz from two wheels are displayed on the screen in real time. Hardware and software as well as the recording trigger signal are described in detail in this paper.

## INTRODUCTION

Manual wheelchair users are at high risk of median nerve injury and carpal tunnel syndrome (CTS) [1]. In clinics, we find that a high percentage manual wheelchair users who experience from shoulder, elbow, wrist, and hand pain. Shoulder related injuries have been shown to be present in up to 51% of manual wheelchair users. The shoulder and wrist pain hamper mobility of manual wheelchair users severely. To gain a better understanding of the mechanism behind CTS, the quantitative measurement and analyze of biomechanics is much important during manual wheelchair users pushing their personal wheelchair [2].

The SMART$^{Wheel}$ is used to investigate the biomechanics of an individual pushing a wheelchair [3]. In some studies, it is necessary collect data from two SMART$^{Wheels}$ at same time. In the past, two computers were needed during moment data collection from two SMART$^{Wheels}$, and the software could not display the force waveforms in real time.

We introduce new method of data collection from SMART$^{Wheels}$. Data from two SMART$^{Wheels}$ could be collected and displayed on a single computer in real time. A digital cameras system was used for kinematic analysis. In order to synchronize data of the digital cameras with data from the SMART$^{Wheels}$, a trigger signal from the digital cameras system was connected to PC parallel port. By reading the trigger signal from parallel port, the software could determine automatically when to begin recording the data from the two SMART$^{Wheels}$.

## HARDWARE

The hardware of data recording system consists of the left SMART$^{Wheel}$, the right SMART$^{Wheel}$, PC, two serial ports PCI interface board, video digitizing system with its trigger signal. See Fig.1.

The left SMART$^{Wheel}$ and the right SMART$^{Wheel}$ are placed on a wheelchair during testing. Each SMART$^{Wheel}$ consists of a plastic composite wheel with three beams attached to the hub. Each beam is instrumented with two sets of strain gages sensitive to perpendicular directions of bending.

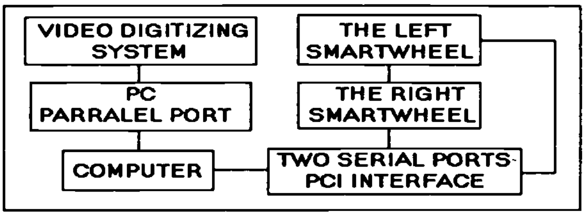


Figure.1 Software diagram of SMART$^{Wheels}$ data collection

An optical rotary encoder is attached to the frame of the wheelchair and is turned by the wheel. The force data is sampled at 240Hz and converted to digital form by a micro controller and transmitted to the PC through two serial ports. The baud rate is 38400 bps. The two serial ports interface board PCI-232/2 was made by National instruments. It contains two 9 pins serial port connectors. The NI serial software is fully integrated into the standard Windows 98/95 communications software. NI serial ports are used like any other Windows 98/95 communications (COM) port. Our digitizing video system is used to collect kinematic data at a frame rate of 60 Hz. The trigger signal from video digitizing system is connected to the PC parallel port to trigger our program.

**SOFTWARE**

Borland C++ Builder 4.0 language was used for our software programming. The language is a fast, powerful ANSI C++ compiler and visual development environment for building high-performance Windows applications. Our software consists of four parts. See Fig. 2. (A) SMART$^{Wheels}$ calibration. Before recording data, we need to check, calibrating each wheel to see if it works properly. In this mode, data from six channels, index and count are displayed on the PC screen. (B) Single SMART$^{Wheel}$ data collection. In this working mode, data from single SMART$^{Wheel}$ data are collected and waveforms of forces Fx, Fy, Fz are displayed at the same time. (C) Two SMART$^{Wheels}$ data collection. Data from two SMART$^{Wheels}$ are collected and waveforms of two wheel forces Fx, Fy, Fz are displayed at the same time. (D) Trigger signal working mode. Start recording data when PC receives the trigger signal from video digitizing system. The software is programmed in Windows 98. Application programming interfaces (APIs) are used for serial port communication. The functions used include opening a port, reading and writing, serial status, and serial setting (DCB, flow control, and communications time-out).

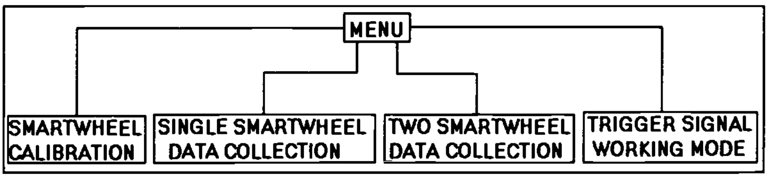


Figure.2 Software diagram of SMART$^{Wheels}$ data collection

The serial communication device-control block (DCB) structure setting is very important. There are different ways to initialize a DCB structure. The function BuilderCommDCB is used in our software to initialize a DCB. This function includes settings of the baud rate, parity test, stop bits, and number of data bits members of the DCB. The function CreateFile is used to open a communication port (We open ports COM5 and COM6 for two SMART$^{Wheels}$). The function

ReadFile issues a read operation. The ClearCommError function retrieves information about a communications error and reports the current status of a communication device. An application need set communications time-outs when it uses a communication port. We use the SetCommTimeouts function specifies communication time-outs.

## RESULTS & DISCUSSION

By using the techniques of data collection introduced in this paper, we could receive the data from two SMART$^{Wheels}$ through two serial ports COM5, COM6 at same time. The baud rate is 38400 bits/s for each wheel. The hardware connections for signal ports and trigger are simple. It is much easier to calibrate the two SMART$^{Wheels}$ in our new system. Compared to the software of DOS version, the new software is much friendlier. More information is given in the new system. Waveforms of two SMART$^{Wheels}$ forces could be displayed at real time while collecting data. There is a higher signal to noise ratios in the data we received in new system. No data are lost despite of the higher baud rate. Fig. 3 is the form of receiving data from two SMART$^{Wheels}$.

SMART$^{Wheels}$ are often used in the studying of quantitative measurement and analyze of biomechanics for the manual wheelchair. There is no database and data analyzing function in our data collection software. Now we use MATLAB software for our data analyzing. Adding database and analyzing parts should improve future software. So it is convenient for user to search some important information.


Figure. 3 Form of receiving data from two SMART$^{Wheels}$

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## CONSIDERING GENDER DIFFERENCES IN MANUAL WHEELCHAIR PROPULSION KINETICS: USE OF A PUSHRIM FORCE RATIO

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### ABSTRACT

Previous work has demonstrated gender differences in the anthropometric[1], kinematic[2] and kinetic[3] features of manual wheelchair propulsion. This work showed a statistically significant difference in the average pushrim force production between genders. An indication of the exertion relative to a maximal effort may be found by comparing the force production for typical propulsion speeds with that generated when starting from rest with maximal effort. This study monitored the force applied to the wheelchair pushrim during four propulsion trials in which the subjects propelled at a self-selected speed, 2 mph, 4 mph, and from rest with maximal effort. Recorded force values were normalized relative to weight. Differences in the proportion of force required relative to the force exerted at start-up became more apparent between gender groups as the speed of propulsion increased. Differences between genders were statistically significant for the four (4) mph trials ($p=0.007$) and trended toward significance for two (2) mph trials ($p=0.134$).

### BACKGROUND

Few studies have reported on gender differences in the dynamics of wheelchair propulsion. This is despite its possible impact on clinical decisions regarding manual wheelchair prescription, configuration and training. Prescription of a manual wheelchair requires consideration of the planned daily use and prognosis of the customer's condition. Configuration of the manual wheelchair directly affects the stability[4], rolling resistance[5], range of motion[6] and force[6] required to move the wheelchair. Training, while often ignored, can instruct a new user in the most efficient methods of applying force to the pushrim. With all of these factors, the goal is to reduce number of propulsion strokes and the amount of force exerted on the pushrim. It is believed that fewer propulsion cycles and lower pushrim forces may correspond to a reduced rate of long term injury such as distal clavicle osteolysis, rotator cuff tears, tendonitis and nerve entrapments (cubital tunnel syndrome and carpal tunnel syndrome).

Previous work comparing the average maximum force produced at the pushrim has shown differences between genders when propelling the wheelchair at speeds of two (2) mph ($p=0.03$) and four (4) mph ($p=0.02$).[3] The number of propulsion strokes to maintain each speed trended toward a significant difference with females having a higher stroke frequency. Possible clinical ramifications of these findings were demonstrated in a recent study in which significantly more females experienced degeneration of the shoulder over time.[7] This degeneration was related to inefficient biomechanics. For the current study, the percent of maximum force that must be generated to maintain common propulsion speeds is considered. It is the authors' opinion that the need to produce a greater percent of maximum effort during daily use may contribute to the noted clinical findings.

## METHODS

Upon giving informed consent, 20 adults (10 female, 10 male) with SCI (T5 average level) propelled their daily use wheelchair on a two-roller dynamometer. The wheelchair was fitted bilaterally with the force sensing SMART$^{WHEEL}$s and standard anodized aluminum pushrims (Figure 1). Propulsion trials were performed at a self-selected speed, 2 mph and 4 mph with data collected for 20 seconds after the speed had reached a steady level. In the last trial, subjects were asked to start from rest and accelerate with maximal effort to 4 mph. Subjects received vocal encouragement during the maximal effort trial.

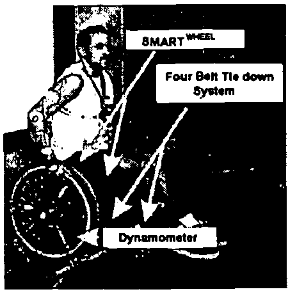

Figure 1: Experimental Setup

Subjects were matched based on anthropometric percentile data of height, weight and body-mass index[8]. Data from left and right SMART$^{WHEEL}$s were averaged after it was determine they were highly correlated. Data for the constant velocity trials were analyzed to determine the mean peak force applied to the pushrim during the first five strokes. These mean values and the maximum force applied to the pushrim for the start-up stroke were normalized with respect to body weight since weight has been demonstrated to be a confounding factor.[9] Ratios were computed for each force value from the constant velocity trials relative to the start-up trial. The ratio provides insight into the amount of force required to maintain each respective velocity relative to the maximal effort to start from rest. Distributions were calculated for each group and comparisons were performed using a Student's t-test (table 1).

**Table 1: Force Ratio Distribution Statistics**

**FEMALE**

| | Mean | SD | Min | Max |
|---|---|---|---|---|
| Self-Select | 0.203 | 0.07 | 0.10 | 0.32 |
| 2 mph* | 0.215 | 0.09 | 0.11 | 0.37 |
| 4 mph** | 0.324 | 0.10 | 0.12 | 0.50 |

**MALE**

| | Mean | SD | Min | Max |
|---|---|---|---|---|
| Self-Select | 0.179 | 0.06 | 0.09 | 0.29 |
| 2 mph* | 0.169 | 0.03 | 0.11 | 0.21 |
| 4 mph** | 0.21 | 0.05 | 0.11 | 0.29 |

(* p=0.134, ** p=0.007)

## RESULTS

The analysis using Student's t-test is summarized in table 2. Considering data in both tables 1 and 2, females required a higher proportion of the force relative to the maximum to maintain each respective velocity than did males. Of interest is the increasing nature of the ratio for females from the self-select through to the four (4) mph trial. Alternatively, males demonstrated a decrease from self-select to two (2) mph and a slight increase in moving to a higher speed at four (4) mph. This can be explained in that the average speed of women and men is the self-select trial were 1.8 mph and 2.2 mph respectively. Of greatest interest is the significant jump in the ratio of females when propelling during the four (4) mph trial.

## CONCLUSIONS

These results demonstrate females tend to use a greater proportion of force produced when starting from rest than do males to maintain a constant velocity. This proportion increases with increasing speed of propulsion until it is statistically significant at four (4) mph. Similar gender differences have previously been shown relative to absolute kinetic values of wheelchair propulsion[3] and may be related to a higher incidence of shoulder degeneration in females over time.[7] Such results indicate the need for clinicians to consider gender and the resulting anthropometric, muscularity, kinematic and kinetic differences in prescribing manual wheelchairs. For example, females may propel more efficiently if given vinyl-coated pushrims which have been shown to increase the propulsive force transferred to the wheelchair[10]. Such clinical applications may allow both men and women to use manual wheelchairs without incurring cumulative injuries.

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# A SURVEY TO SUPPORT THE DEVELOPMENT OF AN INTERFACE DEVICE FOR INTEGRATED CONTROL OF POWER WHEELCHAIRS, COMPUTERS, AND OTHER DEVICES

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## ABSTRACT

A survey was developed to provide professional and consumer input into the design and development of an interface device for integrated control of power wheelchairs, computers, and other devices. The purpose of the survey was to collect and analyze data on the various components considered essential in the design of a prototype integrated controller. The web-based survey allowed for recruitment, consent, and survey completion to occur through the Internet or e-mail exclusively. Survey results indicate a strong desire for the use of integrated controls.

## BACKGROUND

Many people who rely on powered wheelchairs have limited abilities to physically control a variety of needed output devices to perform common daily activities (1). A person with high-level spinal cord injury, who controls a powered wheelchair with a proportional chin mounted joystick, might need a computer for educational, vocational, or personal pursuits. A person with cerebral palsy, who controls a powered wheelchair with a proportional joystick operated with one foot, may need to control an augmentative and alternative communication (AAC) device.

In these and other cases, the clinician and consumer often identify only one control site as reliable, effective, and acceptable relative to performance and comfort. In addition, controllers and devices require space in an already limited "real estate" available to the user. Current technology solutions to multiple assistive device needs necessitate the use of either separate or "distributed" controllers placed in different locations or separate controllers interchanged at the same location. Consequently, the use of distributed controls results in cumbersome arrangements of input devices or may limit the number of assistive devices that an individual can operate (2).

Development of integrated control systems has attempted to address the problems of distributed controllers (3, 4). However, these systems have not developed or evaluated a universal interface technology. In addition, minimal information is available which identifies factors for recommending appropriate integrated controls (2). Tools for monitoring the access rate for comparing various input methods for AAC users are just now becoming available (5).

Some wheelchair control systems offer the option of an "environmental control" function. This typically provides four switch outputs that can be activated when the wheelchair joystick is moved in the corresponding directions (up, down, left, right). Accessory items are available that use those switch outputs. For example, those switch outputs may be converted to mouse emulation for use with a computer or AAC system. However, since the proportional information available from the joystick position has been reduced to four switches, pointing performance has been reduced as well.

**OBJECTIVE**

A Likert-type survey was developed and distributed as part of a RERC project encompassing the design, development, and evaluation of strategies and devices to promote the electronic integration of external devices with powered wheelchairs and the single control of these devices, ensuring their compatibility and usability. The purpose of the survey was to collect and analyze data on the following issues considered essential in the design of a prototype integrated controller:

- identification of all major proportional control formats used in powered wheelchairs, computer access, AAC, robotics, entertainment, and other areas of assistive technology;
- identification of specific outcomes that lead to the definition of the control bus adapter(s).
- determination of whether multiple adapters are more commercially viable than a single adapter that does everything.

**METHODS**

After survey development, a recruitment announcement was distributed through email and the Internet including the following listserves: 1) the RESNA SIG-11/09 listserves, 2) WheelchairNet listserve, and 3) ACOLUG (Augmentative Communication On Line User Group) listserve,

Participants fell into the categories of consumers and professionals. Consumers were considered users of powered wheelchairs with proportional control. Professionals included service providers to consumers who would benefit from integration of electronic external devices, individuals pursuing research in the development of controllers for assistive technology, and manufacturers.

The project began when the investigator activated the web site for the completed survey and posted recruitment notices. Upon receipt of a recruitment announcement as a listserv posting or personal e-mail message, potential respondents were asked to return e-mail consent. Upon receipt of consent, the sample respondents were given the web site address and password for the survey. Security measures in designing the web site and providing a password controlled access to the site and avoided duplication of responses.

The survey required approximately 20-30 minutes for completion. No response was associated with a particular individual, and the data was tabulated and analyzed in a manner to insure confidentially and anonymity of participants.

**RESULTS**

Data from 14 professional respondents were analyzed using descriptive statistics. Clinical service providers made up the majority of professional respondents (61%) and the second largest group was researchers (23%). Only one manufacturer and one supplier completed the survey. In addition, five consumers completed the survey.

All of the professional respondents felt that an integrated device would be useful for their clients. In addition, 100% of the respondents felt that an integrated device would be useful for people with disabilities in general. When asked to identify which was more useful for the client, a single integrated control or multiple device adapters, 83% identified a single all-purpose integrated control and 17% preferred the availability of multiple device adapters.

The following functions/options that should be performed by an integrated control were identified on an open-ended question: computer access/mouse (92%); ECU/EADL control (54%); AAC control (38%); wheelchair accessories (31%); switches/scanning abilities (23%). Additional single responses included the following suggestions: removable from chair, auto detection of device, user parameter adjustments, ability to control more than one device at a time.

Respondents identified the following communication protocols for use or access: Universal Serial Bus (USB), Apple Desktop Bus (ADB), Infrared (IRDA), parallel port/serial port (RS232), Radio Frequency (IEEE standards or/Bluetooth), General Input Device Emulating Interface (GIDEI). In addition, safety concerns included the following suggestions: clear indication of what device is in use; immediate "kill switch"/emergency shut off; backup/emergency access; interference with other devices.

Consumer responses were in agreement with features and functions for an integrated controller as well as concerns about safety. Only two respondents had tried an integrated control to operate multiple devices. Of these, one found the controller to be very easy to use, while the other respondent found the controller to be difficult to use. Three respondents were interested in using their wheelchair controller to control other devices. The respondents indicated a preference for using an integrated controller for environmental control and computer access.

## DISCUSSION

The results from this survey confirm the market interest in integrated controls. While the expected performance improvement as a result of a true proportional control is as yet unknown and therefore unappreciated, the survey results provide some justification for the continued development of integrated controls.

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# PRESSURE RELIEVING MOVEMENTS MADE DURING SLEEP: DO THESE OCCUR DURING WINDOWS OF OPPORTUNITY

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## ABSTRACT

An investigation into the turning patterns of 20 normal, healthy subjects was undertaken. Tissue-interface pressures at 10 pressure sore prone anatomical landmarks were measured continuously throughout each sleep study. The subjects' sleep stages were ascertained and their recumbency positions measured (1). The $tcpO_2$ levels of the subjects were measured for different levels of applied pressure and the tissue-interface pressures were interpreted in terms of anoxic status. Results indicated that the turning of the subjects was related to REM-NREM transitions but that the incidence of the movements was linked to levels of tissue anoxia. A logarithmic relationship between maximum period of immobility and predicted tissue anoxic level was postulated.

## BACKGROUND

Amongst those concerned with the study of pressure sore formation, it is a long held belief that their onset is due to prolonged periods of interference in the supply of nutrients and the removal of metabolic waste via both the circulatory and lymphatic systems. The nature of the interference is applied pressure whose minimum level is within the range 32 mmHg to 60 mmHg (2), and is applied over a period of time (3). Significantly, Exton-Smith & Sherwin (4) found that patients were unlikely to develop a pressure sore if they made 20 or more turns in a period of 7 hours.

However, those concerned with the measurement of the sleep process and circadian rhythms, consider movement during sleep to be a directly related function of the process. This belief is so firmly held that many investigators have tried, with varying degrees of success, to use movement related signals as a substitute measurement for the more complex and time consuming method of polygraphic recording and analysis of the EEG. Sleep researchers generally classify movements made, into major movements (gross turns and major shifts), minor movements (movements involving a single limb, or small shifts) and twitches (nocturnal myoclonic activity (5)). It has been known for some time that major movements occur during the left-right hemisphere desynchronization of the EEG (6). Of these, many have been observed to be major shifts in posture. Dzvonik et al (5) carried out a study to try to provide evidence for the triggering mechanism in periodic movements during sleep (PMS). Although their primary measurement was nocturnal myoclonus (leg jerks) their apparatus also allowed the identification of major changes in body position, including pressure relieving major turns. Explanations of the phenomena had previously been proposed based on the absence of the movement inhibitory mechanism (7) during sleep. They reported that the movement cycles were periodic, NREM related and positively related to age. Dzvonik's analysis hypothesised that PMS episodes were triggered by adverse body positions or reduced tissue perfusion possibly due to applied pressure, and that they continued until the applied pressure had been reduced, or removed, and the tissue had been reperfused.

## RESEARCH QUESTIONS

The aim of this study was to marry the techniques of continuous overnight tissue-interface pressure measurement (interpreted as $\%pO_2$)with measurements of the REM-NREM cycle. It was hoped that the information gathered from these experiments would shed light on the dichotomy of the viewpoints of the above two 'scientific camps'. In particular was Dzvonik's hypothesis correct and were Exton-Smith and Sherwin correct in their assertion that turning recumbent patients approximately every 20 minutes prevented pressure sores?

## METHOD

A sound monitored and temperature controlled sleep laboratory was set up, with additional equipment to continuously measure tissue-interface pressure (DPM 2000) at known pressure sore prone anatomical landmarks and subjects' recumbency positions, using a Tele-Bug (1). Further to this a pressure applicator with in-situ $tcpO_2$ sensor (1) was used to characterise applied pressure in terms of tissue perfusion. Sleep stages were identified from EEG/EOG and wrist movements.

Two mattress surfaces were used in the study; a 'firm' foam mattress (Surface A) and a pressure relieving mattress (Surface B). The choice of mattresses was designed to produce a large difference (statistically significant at $p = 0.0001$) between the tissue-interface pressures measured on each surface, thus hopefully accentuating differences in response mechanisms to ischaemia.

### *The Subject Group*

Twenty adults (10 male and 10 female) entered the study, with a mean age of (33.7±2.3) years.

### *The Entry and Rejection Criteria*

The entry criteria for the subjects comprised the following:- A subject age range of 30 to 39 years. This criterion was based on the results of a previous study into spontaneous turning with age (8), as the 30s' age group was the first whose maximum turning interval existed in the *stable plateau* region of the age related trend. The subjects were required to be in good health, in particular, free from vascular disease and free from current medication, have no history of sleep related disorders or psychological complications and should not have consumed alcohol within 48 hours of the study, nor should the subjects have taken vigorous exercise within 24 hours of the study. Normal levels of blood pressure were also required (9).

The rejection criteria included the following:- The subjects should be recumbent for a minimum of 7 hours on two consecutive nights. The subjects should not be aroused or disturbed by extraneous noises ≥ 40 dBA (10) and should not be aroused by changes in lighting levels (11).

## RESULTS

After establishing subject normative data and confirming the negligible influence of measurement techniques and equipment, data from 15 subjects who met the entry criteria and passed the rejection criteria were included in the final analysis (paired T-tests used unless otherwise stated).

### *Analysis of the Results*

Many parameters for each surface were analysed including; the mean maximum period of immobility, the mean tissue-interface pressure (for the maximum period of immobility per night), the mean $\%pO_2$ level (for the maximum period of immobility per night), the REM-NREM cycle length and the %REM per night. Additionally, measurements of sleep quality were also analysed.

No significant difference was noted in the subjective quality of sleep analysis or that the levels of anoxia, even on the firm mattress, affected the subject's *sleep* as defined by the %REM and REM cycle period parameters, as both parameters were found to be not significantly different from quoted standard values (11). It is reasonable to conclude therefore that tissue anoxia is subjugate to the REM-NREM cycle.

The main objective of this analysis was to establish whether gross turning occurred during REM-NREM cycle transitional periods and if so was independent of external factors such as tissue anoxia. It was reasoned that if the turning was independent, little or no correlation would exist between the percentage of spontaneous turns associated with the sleep stage transitions and the anoxic level of the tissues, or factors contributing to the anoxia. The method of analysis employed was to identify two time 'windows' that were related to the REM-NREM cycle. Gross turns occurring within these windows would be said to be instigated by the sleep stage transition. If a statistically significant difference in the percentage of turns associated with the stage transition was found with varying external factors, then the conclusion must be that although spontaneous turning was linked to the phase transitions, these periods did not necessarily trigger the turn. The corollary to this was that the transitional periods provide *windows of opportunity* for turning, triggered by other factors. It was found that at $p = 0.0001$ the total percentage of REM transitions associated with turning was influenced by the surface on which the subjects slept. Another significant factor was the difference between the mean maximum periods of immobility on the two surfaces ($p \leq 0.001$). The mean maximum period value of 122.2 min on surface B was not found to be significantly different from that found in another study (1) at 139.6 min. However, the mean maximum period of immobility on the surface (A) was 63.1 min (example traces of one subject's $\%pO_2$ ($tcpO_2/tcpO_{2\ unloaded}$) for each maximum period of immobility can be seen in Figure 1).

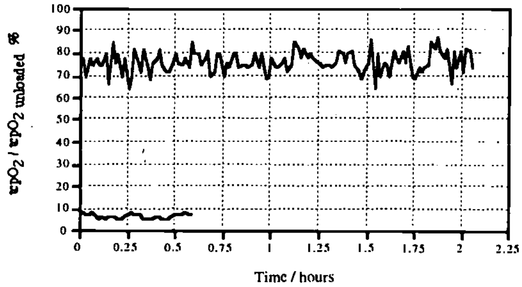


Figure 1. Surface A. Lower trace Surface B. Upper trace

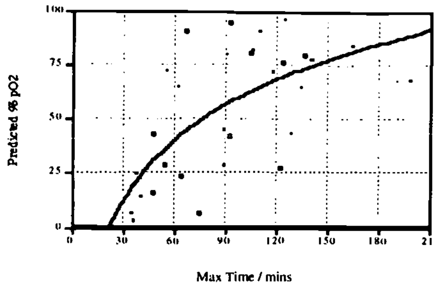


Figure 2. $\%pO_2$ versus max period of immobility

When this parameter was correlated with each mean $\%pO_2$ for each episode the above scatter graph (Figure 2) was ascertained. The following logarithmic equation of fit was postulated:

$$\%pO_2 = 92.7 \, Log \, (immobility \ period) + 123.9 \qquad (r^2 = 0.65)$$

## DISCUSSION

Utilising the above equation of fit, at the boundary conditions the $\%pO_2$ = 100% and 0%, the predicted maximum periods of immobility are 260.9 min and 21.7 min respectively. This latter condition correlates extremely well with observations made by other investigators in this field; notably Exton-Smith & Sherwin. A point worthy of note is that the two mean measurements of maximum period of immobility for each surface lie either side of the mean REM cycle length (96 min). This correlates well with the percentage of REM cycle transitions that triggered an associated turn on each surface. The *window of opportunity* hypothesis has some merit, as clearly, maximum periods of immobility well in excess of the REM cycle length occurred frequently. On inspection of the pressure-time tracings it can be seen in some instances that movements have occurred even though a pressure relieving turn of more than 30° has not. This lends credence to the supposition that turning (for whatever reason) is a demand driven exercise and as such, any factors that influence the circadian cycle (e.g. the administering of cytotoxic drugs) will also affect the body's ability to react spontaneously to tissue anoxia due to applied pressure, whilst asleep.

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## COMPARATIVE EVALUATION OF PRESSURE MAPPING SYSTEMS (1): BENCH TESTING RESULTS

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### ABSTRACT

In order to help seating practitioners assess the seated posture and pressure distribution needs of wheelchair users there are a variety of real-time objective pressure mapping devices available. It is imperative that the performance of these devices is known in order that results can be interpreted correctly and results from using different systems may be comparative. In this paper, we have bench tested three pressure mapping devices from Tekscan, Xsensor and FSA providing data on hysteresis, reproducibility, creep and rate of response. The results show that the performance of pressure mapping systems has improved since a report in 1993 by Ferguson-Pell and Cardi and that there is little to choose between them based on these test results. This work is ongoing as part of an ISO standard for wheelchair seating. Further tests are in progress to establish performance using contoured loading strategies and these will be presented separately.

### BACKGROUND

Over the past several decades wheelchair manufacturers have been providing an increasing variety of seating products that provide improved body support and injury prevention for the wheelchair user. In order to help seating practitioners arrive at a solution appropriate to the needs of the wheelchair user there has also been an increase in the variety of measurement devices available to give real time communication of anthropometric measures and interface pressure distribution. It is imperative that the performance of these devices is stated allowing the seating practitioner and manufacturer to interpret results, understand their limitations and compare performance between different systems.

In 1993 a study was carried out by Ferguson-Pell and Cardi (1) on the performance of wheelchair pressure mapping systems available at that time. Since then technology, fabrication methods and materials available for their development has improved and software programming techniques have advanced. This has allowed some of the findings of that study to be addressed with the improvement and introduction of new pressure mapping systems. As pressure mapping techniques are being used increasingly in the clinical setting for prescription of wheelchair cushions it is timely that their performance should be re-evaluated and compared.

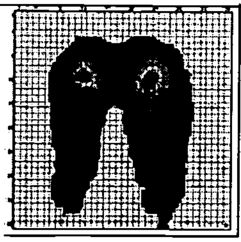
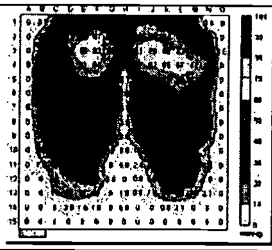
This work is being completed as part of the development of an ISO (International Organization for Standardization) standard in wheelchair seating. It is being prepared as part of Technical Committee TC 173 " Technical Systems and Aids for Disabled or Handicapped Persons", Sub committee SC-1-Wheelchairs, Working Group WG-11-Wheelchair seating. This involves bench tests to determine accuracy, hysteresis, repeatability/reproducibility, stability, creep, rate of loading response and mat artifacts (i.e. effect of mat on applied load shape, effect of drape such as kinking and hammocking), environmental effects, calibration stability and contoured loading performance.

### RESEARCH QUESTION

The objective of this study was to determine the performance characteristics of three types of pressure mapping systems, providing information on hysteresis, repeatability, stability/creep and rate of loading response.

## METHOD

Equipment

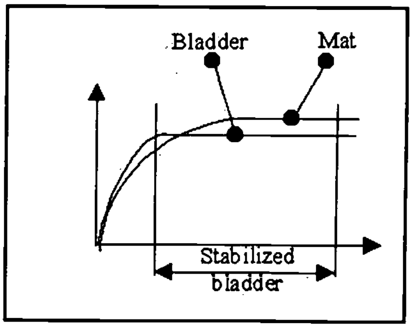
| System | Tekscan | Xsensor | FSA |
|---|---|---|---|
| Manufacturer | Tekscan Inc. Boston. US | Xsensor Technology Corporation, Calgary, Canada | Vista Medical, Winnipeg, Canada |
| |  |  |  |
| Sensor type | Conductive ink | Capacitive | Conductive rubber |
| Single sensor area | 103 $mm^2$ | 135 $mm^2$ | 298 $mm^2$ |
| Sensor pitch | 10 mm | 13 mm | 25 mm |
| Number sensors | 1558 | 1296 | 225 |

Bench tests

*Calibration.* Each pressure mapper was calibrated according to the manufacturer's instructions using the FSA calibration apparatus with the mapper and air bladder sandwiched between two wooden platens.

*Hysteresis and repeatability.* Planar loads were applied in increments of 20 mmHg from 0-200-0mmHg. The loading rate was one 20 mm Hg increment every 10 seconds with a 10 second delay at each increment. The tests were repeated twelve times removing and reinserting the pressure map between each repetition. Output measurements for each loading cycle were recorded and hysteresis was disclosed by measuring the difference between ascending and descending traces at 50, 100 and 150 mmHg. Repeatability was disclosed as the coefficient of variation for the readings obtained at 50, 100 and 150 mm Hg in the 12 tests.

*Stability/creep and rate of response.* Pressure was applied by ramping to 100 mmHg in 10 seconds without overshoot and constantly applied for ten minutes. A continuous electronic recording of the applied pressure and output readings was taken at a sampling rate of 1 frame/second. Stability was disclosed by expressing the change in output after 10 minutes of stabilization from the instant the applied pressure level was reached. Rate of response was disclosed as the ratio of the response time of the pressure mapping system to the bladder pressure to reach 100 mmHg.



## RESULTS

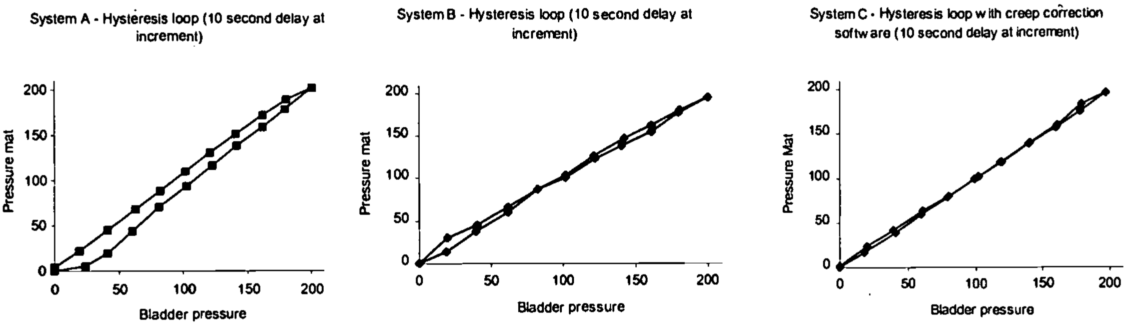



Figure 1. Hysteresis curves for A) Tekscan, B) Xsensor and C) FSA.

Table. Summary of bench test results

| Parameter | | Tekscan | Xsensor | FSA |
|---|---|---|---|---|
| Hysteresis | 50 mmHg | 24.6 mmHg | 5.6 mmHg | 3.5 mmHg |
| | 100 mmHg | 17.3 mmHg | 3.1 mmHg | 0.6 mmHg |
| | 150 mmHg | 12.2 mmHg | 7.5 mmHg | 5.8 mmHg |
| Repeatability | 50 mmHg | 14.2 % | 4.0 % | 1.8 % |
| | 100 mmHg | 3.0 % | 2.8 % | 1.8 % |
| | 150 mmHg | 0.9 % | 1.3 % | 1.7 % |
| Stability/creep | 100 mmHg | 20 mmHg | 2.8 mmHg | 1.8 mmHg |
| Response time | 0-100 mmHg | 0.5 | 0.4 | 1.0 |

## DISCUSSION

These bench test results demonstrate how current pressure mapping systems show smaller hysteresis and creep values than marred earlier versions and made practitioners and researchers wary of using them. The Xsensor and FSA have hysteresis at 100 and 150 mmHg < 5 % with repeatability < 4 %. The FSA exhibits < 2% creep over 10 minutes at 100 mmHg. The Tekscan showed higher hysteresis and creep values and these results are being investigated with respect to the calibration rig used; the system was shown to have much better performance using a smaller air bladder (results not shown). The manufacturers suggest air entrapment within the sensor may be responsible for the performance observed. This highlights the need to adopt correct bench tests to adequately assess performance and work is ongoing to define standard test methods for incorporation as an informative annex in the ISO standard. These results provide basic information on pressure mapper performance. In order to assess the performance of these pressure mapping systems in a more applied manner, tests are being conducted using soft contoured loading indentors and these results will be presented separately.

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# COMPARATIVE EVALUATION OF PRESSURE MAPPING SYSTEMS (2): CUSHION TESTING

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## ABSTRACT

The availability of a number of pressure mapping product raises the concern that different results may be obtained from different mapping systems. This has implications for both clinical decision making, and the disclosure of seating system performance characteristics by cushion manufacturers. In Part 1 of this series of abstracts we discussed the performance of pressure mapping systems subjected to highly controlled bench tests using a calibration rig. In this part the cushions were tested under loading conditions designed to simulate normal use. Each of the pressure mapping systems were loaded using a cushion loading indentor (Gelbutt, Beneficial Design, Santa Cruz, USA) on a range of different wheelchair cushions. The results indicate that when the pressure values are summed and multiplied by the active sensor area (measurement of the applied force) the three pressure mapping systems tested indicate an applied force that is within 10% of the known applied force for the range of cushions tested.

## BACKGROUND

In 1993 a study was carried out by Ferguson-Pell and Cardi (1) doubts were raised as to whether pressure mapping systems could rank a set of cushions in the same order, let alone provide reliable quantitative information about them. The difficulties they experienced could have been a consequence of using human subjects to load the cushions. Poor repeatability of human subject tests has been reported (3) and therefore reduces statistical confidence in comparing the results. The use of buttock shaped indentors (1,2,3,4,5) offers an opportunity to improve the repeatability of these tests and compare the performance of the different pressure mapping systems.

This work is being completed as part of the development of an ISO (International Organization for Standardization) standard in wheelchair seating. It is being prepared as part of Technical Committee TC 173 " Technical Systems and Aids for Disabled or Handicapped Persons", Sub committee SC-1-Wheelchairs, Working Group WG-11-Wheelchair seating.

## RESEARCH QUESTION

The objective of this study was to compare the results obtained from three pressure mappping systems (Tekscan Inc. Boston US; Xsensor Technology, Calgary Canada; FSA, Vistamedical Winnipeg Canada) when loaded using the Gelbutt on a range of pressure mapping sytems. These initial tests sought to determine whether current pressure mapping systems could accurately indicate the total applied force for a wide range of cushion types.

## METHOD

The Gelbutt consists of a buttock shaped undersurface fabricated using a proprietary mix of urethane gel. A replica human pelvis is positioned within the gel to produce loading distributions similar those produced by human subjects. The top surface of the Gelbutt is a rigid plate marked with a central datum. In order to use the Gelbutt it is necessary to fabricate a loading rig to apply the indentor section with known loads and with the orientation of the Gelbutt relative to the cushion carefully controlled. A simple rig was fabricated using a bi-directional pneumatic piston and a metal frame (see Figure 1).

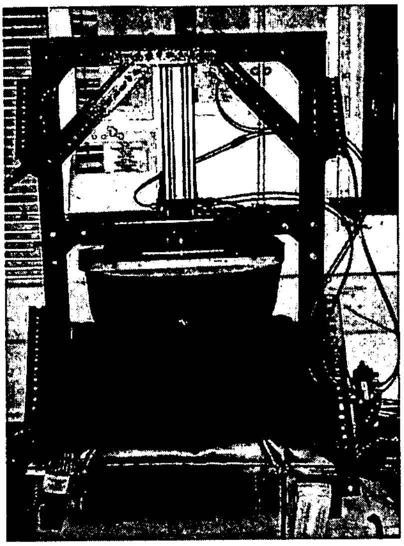

**Figure 1.** Gelbutt and loading rig prepared for loading. An airbladder (used in ISO tests for inter-center comparision) is in position with an AF FSA pressure mapping system placed on top.

For these tests the Gelbutt was fixed in a horizontal position relative to the support for the cushion. A total load of 570N (including the weight of the Gelbutt) was applied to each cushion tested. All the pressure mapping systems were calibrated up to 200 mmHg according to the manufacturer's specifications using the FSA calibration rig which employs an airbladder inflated between two fixed plywood platens. The applied load was determined by placing a calibrated scale (similar to bathroom scale) under the Gelbutt. Air pressure controlled by a regulator was applied to the piston until the scale reached the required load. The required pressure was noted and repeatability tests performed. The applied load was noted to remain within 250g of the specified load yielding a variation of less than +/- 0.5%). The repeatability of the Gelbutt loading system was tested by loading a Tekscan system on an inflated air bladder. The peak pressure under the ischium (left) was selected as an anatomically meaningful site. The peak pressure parameter was chosen since it is sensitive to small variations.

A range of 8 cushions was selected. Each cushion was new when tested and was preconditioned by applying 2 cycles of uniform load at 850N. The pressure mapper was then placed on top of the cushion and the Gelbutt applied rapidly at the prescribed load for 60s. The load was then removed rapidly and the system allowed to relax for 60s before repeating the cycle of loading and unloading 5 times for each pressure mapping system.

The results were analyzed by summing the pressure readings and multiplying by the active area of the sensor (or using the total force value presented by the software where available) after 60s of loading for each pressure mapper and cushion combination.

## RESULTS

The variation in peak pressure for 5 repetitions using the Tekscan sensor on an air bladder was 83-86 mm Hg (excluding 1 outlier). The mean was 83.6 mm Hg (s.d. 3.4) and range was 78-86.

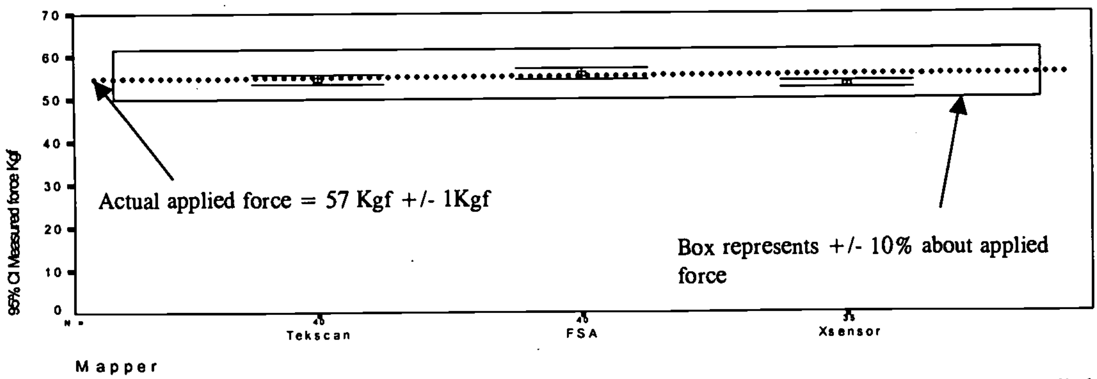


**Figure 2.** Results combined for all cushions indicating the variation for each pressure mapper in measuring the applied force of 570N

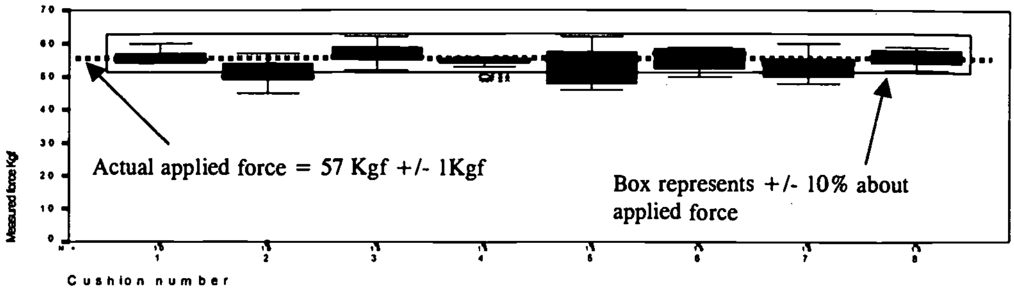


**Figure 3.** Results combined for all pressure mapping systems indicating the variation in measuring the applied force of 570N for each cushion.

## DISCUSSION

These results are a preliminary and encouraging indication that the three pressure mapping systems are able to generate data that is comparable across systems for a wide range of wheelchair cushion types. They also indicate that the pressure mapping systems accurately measure the applied force, again independent of cushion type. These results were obtained with a replica shape of the human buttocks with nominally comparable mechanical properties. It is reasonable to assume that human buttocks that fall within the nominal shape and mechanical characteristics of the Gelbutt would produce comparable results. However it is not safe to *assume* that subjects with very emaciated buttock tissues would produce similar results.

The loading system used was shown to produce repeatable loading conditions when tests were performed on an air bladder. The variation observed was within the anticipated repeatability of the Tekscan pressure mapping system used for the test.

Regardless of the cushion type tested, the pressure mapping systems yielded a calculated total force well within +/-10% of the applied force. This offers an opportunity for standard test methods using pressure measurement to require that the total applied force obtained for the test be disclosed along with other parameters. Should this value fall outside these limits the readings should be considered invalid. The results also indicate that the variability is dependent upon the cushion tested, suggesting that either the pressure mapping systems or the test rig are less repeatable for certain cushion types. The reasons for this variation require further investigation.

These results only consider the variation of one simple parameter according to mapper or cushion used. Further analysis is required to determine whether substantial variations in parameters such as peak pressure, contact area and average pressure occur between mappers and cushions.

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**RISK FACTORS FOR PRESSURE ULCERS: SET IN STONE?**

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## ABSTRACT

Risk assessment tools for pressure ulcers have poor predictive power. Factors which predispose subjects to grade 1 pressure sores may not be the same as those which determine whether a grade 1 sore will progress or resolve. A preliminary investigation of candidate risk factors for progression beyond grade 1 was undertaken. As technology begins to provide objective and accurate means for early identification of erythema, resources may be better deployed at this stage.

## INTRODUCTION

It has long been supposed that pressure sores are preventable[1]. An ideal regime of rigorous turning, effective pressure relief, and good skincare can reduce the incidence, but not eliminate the problem[2]. Furthermore, the reality at ward level is that resources are not boundless. In order to deploy these resources to their best advantage, strategies are adopted to identify patients at risk of pressure ulcers, and take action selectively. A number of scales have been developed to assess patients for pressure sore risk. [3, 4] Unfortunately, shortfalls in validity and reliability of these tools have been identified which seriously undermine their usefulness.

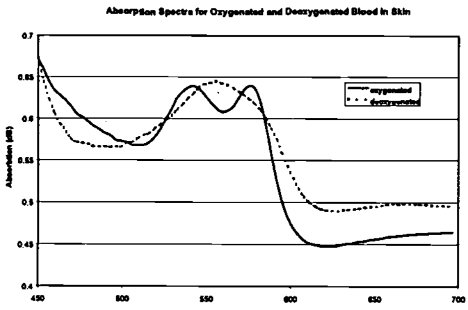


Figure 1

Recent technical advances in tissue reflectance spectroscopy [5, 6,] enable early detection of incipient pressure sores. Figure 1 shows distinct absorption spectra for oxygenated and deoxygenated blood in skin. Algorithms have been developed to distinguish these signature spectra from other materials in the skin such as melanin and collagen. Light reflected from the skin is coded so that blood content and oxygenation may be quantified, even in black skin. This provides a potential means for vital pointers to incipient pressure sores to be identified early and monitored.

Since few incipient pressure sores progress to frank ulceration if they have been identified early and appropriate corrective action has been taken [7], a promising prevention strategy may comprise a combination of early detection of erythema[8] together with revised risk factors for progression. Factors which predispose to grade 1 pressure sores may not be the same as those which predispose to progression beyond grade 1.

## AIMS

This paper describes a preliminary investigation of factors which may be associated with progression of ulcers from grade 1 to grade 2 and above.

## METHODS

60 patients with pressure ulcers at the Whittington Hospital, London, UK were assessed over 2 months, and each followed up for a 2-week period. Parameters assessed included four existing risk assessment tools (Braden, PSPS, Waterlow, Norton) , nutritional status (Burton), anthropometric

quantities, body hair density (Ferriman-Gallwey), grip strength (Jamar hand dynamometer), and medications.

## RESULTS

Of the 60 patients with pressure ulcers, 46 were grade 1, and 14 were grade 2 and above. None of the grade 1 sores progressed to grade 2 during the course of the trial. This may be a result of the attention received by the participants. No significant differences were observed in the existing scoring tools between grade 1 subjects and grade >1 subjects (see figures 2, 3) . Age did not differ significantly between groups. Differences were however observed between grade 1 subjects and grade >1 subjects in grip strength ($p<0.01$) measured using a Jamar hand dynamometer (figure 6) , and body hair density ($p<0.05$), measured using the Ferriman and Gallwey scale, figure 5).

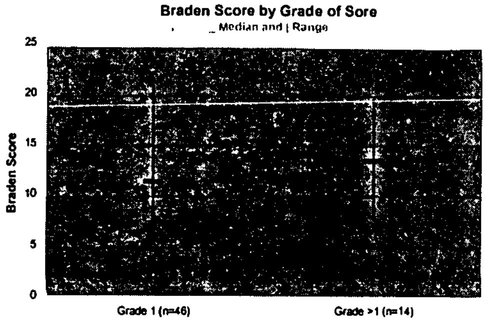


Figure 2

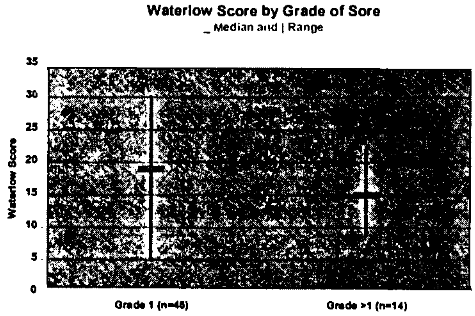


Figure 3

## DISCUSSION

Owing to the large number of parameters monitored during the course of the study, care must be taken in interpreting the significance of findings for individual parameters taken in isolation (at a significance level of $p=0.05$, chance alone will generate a significant finding one time in 20). Numerous plausible mechanisms, however, exist to explain the relevance of grip strength, which warrant further investigation. Grip strength may be an effective indicator of general muscle tone, 'wellness', and neurological integrity. It must be noted that this was not a prospective study, and that measurements were made only after subjects had developed the grade of sore that classified them for the study. Despite the strength of the association, it is therefore not possible to establish a causal link, since decrease in strength may have been subsequent to the progression of the sore.

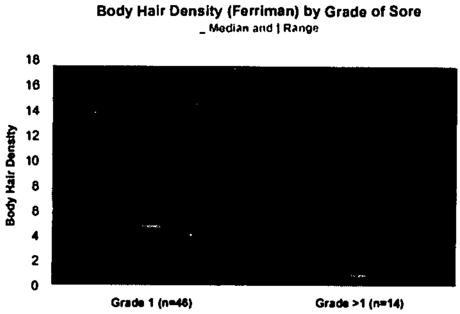


Figure 4

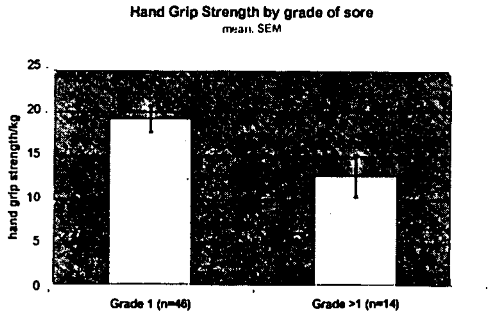


Figure 5

In the case of body hair density, however, it is reasonable to assume that the value will not change appreciably in the short term, and so may be taken to precede the development of the pressure sore. Although the mechanism linking body hair to pressure sore progression is less clear, one possible answer may lie in the microvascular architecture of the skin. The root of each hair follicle in anagen phase is fed by a delicate capillary, which stems from the same arteriolar plexus as those capillaries that feed the dermal papillae (see figure 6). In the case of poor blood supply to the skin, it may be that the hair follicle is one of the first structures to suffer, and may prove useful as a visible indicator.

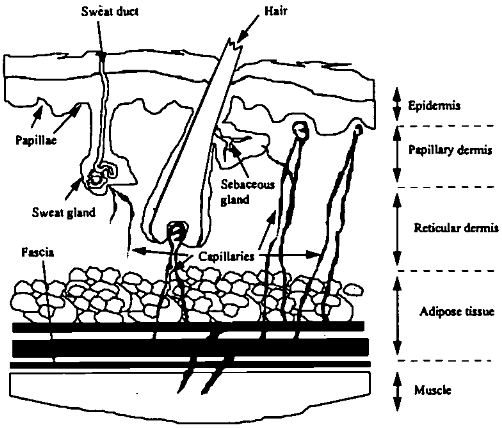


Figure 6

## CONCLUSIONS

Factors which predispose subjects to grade 1 pressure sores may not be the same as those which determine whether a grade 1 sore will progress or resolve. As technology begins to provide objective and accurate means for early identification of erythema, it is important to develop informed strategies for intervention at this stage.

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# DYNAMIC PRESSURE MEASUREMENT AT THE BODY-SEAT INTERFACE DURING WHEELCHAIR PROPULSION

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## ABSTRACT

In addition to a myriad of other factors high normal pressures, of the body-seat interface of wheelchair users, have been shown to lead to the development of pressure ulcers. Historically measurements of pressure distributions on wheelchair users have been obtained under static or quasi-static sitting conditions. The quasi-static testing has been very useful in detecting areas of high pressure as well as aiding in the prescription of new, more appropriate cushions, sitting positions, and wheelchairs. However, there are occurrences of pressure sore development that are not well predicted by this quasi-static measurement technique. In this study, motion analysis has been combined with dynamic pressure measurement in order to determine maximum pressure and pressure distribution at the body-seat interface during the cycle of wheelchair propulsion.

## BACKGROUND

There have been relatively few body-seat pressure studies during dynamic propulsion. Bar (1) investigated the dynamic pressure under the ischial tuberosities over a 2 hour time period with 2 electro-pneumatic sensors. Pressure data showed that relatively small changes in position resulted in large changes in pressure with foam and gel cushions. Kernozek and Lewin (2) evaluated static and peak dynamic pressures of 15 subjects on a Jay Active cushion and found that both static and peak dynamic pressures occurred under one of the ischial tuberosities in all trials. Their data exhibited higher peak pressures during dynamic wheelchair locomotion. These differences in peak dynamic and static pressure were also reported by Eckrich and Patterson (3), who tested able bodied subjects seated without a seat cushion. Dabnichki, and Tatak (4) used a single subject to investigate the pressure variation under the ischial tuberosity during a push cycle. They replaced the seat structure of a wheelchair with a structure containing a Kistler force plate and seated the subject directly on the force plate. Their results showed the peak loads on the force plate to be higher for a series of dynamic tests from slow to fast propelling speeds.

## RESEARCH QUESTIONS

The research questions to be answered with this study were:

1. What is the peak pressure and pressure distribution at the body-seat interface during static sitting and manual wheelchair propulsion?
2. How does the static and dynamic interface peak pressures and pressure distributions compare?
3. How do the dynamic body seat interface pressures correlate with upper extremity and trunk motion during the propulsion cycle?

## METHOD

Nine subjects have been tested thus far. Subjects were positioned, in their own wheelchair and on their own cushion, with a pressure pad positioned under their buttocks. Reflective joint markers were placed on the joints of the arms, the head and chest and on the wheelchair. The subject was then positioned on a roller system in the measurement volume of a Vicon motion analysis system. This allowed for simultaneous kinematic and seat-interface pressure data acquisition. There was a 15 minute time delay prior to the acquisition of the static data. The subject sat quietly while static data was collected for 25 seconds. There was then a 5 minute delay prior to the acquisition of the dynamic data. Then the subject propelled his wheelchair for a 25 second period at 4 mph. During the 20 second period, three-dimensional positioning of the upper body joints, head, and chest were captured using the motion analysis system. These data were then used to provide three-dimensional kinematics of the subject's propulsion behavior. The propulsion testing also allowed determination of the temporal correlation of kinematics of propulsion and pressure distribution.

## RESULTS

The data from the tests were analyzed in three ways. First the dynamic and static pressures of the maximum pressure location(s) (either the ischial tuberosities or greater trochanters) were compared as shown in Fig. 1 for one subject. As seen in Fig. 1 the peak dynamic pressure is less than the peak static pressure. There is an obvious cyclic behavior to the dynamic pressure data. The kinematic data from the motion markers were compared to pressure as a function of time as shown by Fig. 2. For the subjects tested thus far, of all of the kinematic measures, the vertical displacement of the markers on the chest best followed the temporal changes of dynamic pressure. This occurred regardless of the location of high pressure (e.g. ischial tuberosities, greater trochanters, or the sacrum).

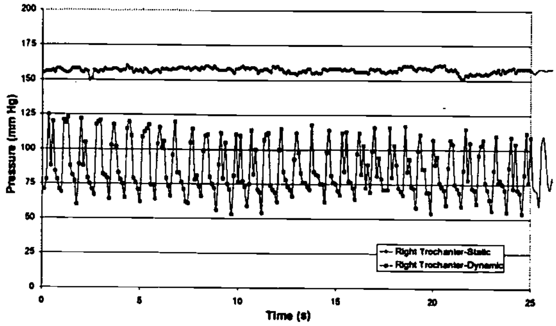


Figure 1. Comparison of Static and Dynamic Pressures at High Pressure Location

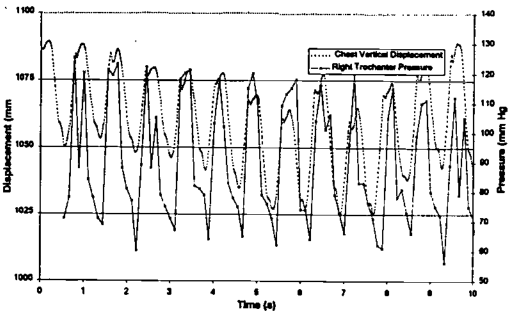


Figure 2. Comparison of Chest Displacement and Greater Trochanter Pressure

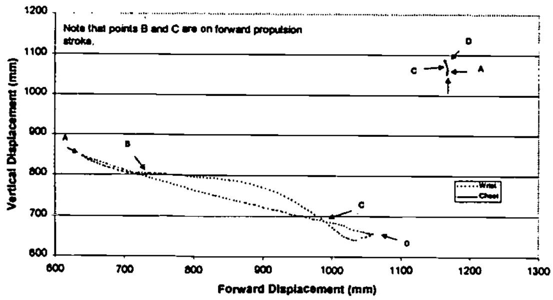


Figure 3. Trajectories of Right Wrist and Chest

Additionally, trajectories of the markers were also investigated to aid in understanding of the cyclic behavior of the pressure response. Figure 3 shows a combined look at the trajectories of the right ulnar styloid and one of the chest markers for the first full cycle captured. Points A-D are labeled on the wrist trajectory in order to compare to locations on the chest trajectory. The chest marker utilized was 80 mm from the sternum. Thus, while the motion of this marker from the sagittal view appears to be largely vertical displacement, it is in fact predominately rotation of the chest.

## DISCUSSION

The peak pressure under static conditions was higher than that under dynamic conditions. However, our previous studies of the creep response of the FSA Ultrathin Mat (Vista Medical) show that the actual static pressure values for the subject would be approximately 16% lower than those displayed in Fig. 1 when corrected for creep. Additionally, from our studies of creep, the dynamic pressures are attenuated by the dynamic response of the pressure measurement system. Thus, the peak and minimum pressures measured by the system are respectively lower and higher than the actual body-seat interface pressures. In the future, estimation of the actual interface pressure values will be performed with our knowledge of the creep response of the pressure measurement system. Figures 2 and 3 show that pressure distribution changes cyclically with trunk movement and position, with the greatest pressures occurring posteriorally under the sacrum, greater trochanters, or ischial tuberosities when the trunk is upright and the arms are at the beginning of the forward motion stroke.

Further understanding of the dynamic peak pressure and pressure distributions at the body-seat interface and correlation with the kinematics of propulsion will lead to improved cushion and posture choices for the manual wheelchair user. Modification of propulsion form may also be indicated for improving pressure distribution and decreasing peak pressure during propulsion.

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## ACKNOWLEDGMENTS

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# THE EFFECT OF KNEE-FLEXION ANGLE ON WHEELCHAIR TURNING

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## ABSTRACT

The increasingly popular hyperflexed knee-flexion position was evaluated to determine its effects on wheelchair turning. The effects of full knee extension and flexion were compared. We found knee flexion increased angular velocity (spinning 720° in place) by 40%, and was perceived to be 66% easier by subjects. Overall length of the wheelchair decreased by 39%, the anteroposterior position of the center of mass (COM) moved rearward 38%, and rolling and turning resistance decreased by 21% and 17% respectively. Rear-wheel traction increased by 12% and the modeled moment of inertia decreased by 42%. We conclude that knee-flexion angle has a clinically significant effect on wheelchair turning. These findings have implications for wheelchair design and prescription.

## BACKGROUND

No research has been published on the effects the increasingly popular hyperflexed knee-flexion position on wheelchair performance measures, including wheelchair turning. Potential negative effects include decreased venous return, the development of pressure sores, an increased risk of casters striking the feet and the development of knee-flexion contractures. Potential positive effects include the ability to move closer to objects, complete tighter turns, protect the feet and transport the wheelchair more easily. In addition, turns about the yaw axis should be faster and more easily performed due to the probable effect of knee flexion on the moment of inertia.

## RESEARCH QUESTION

Our primary hypothesis was that wheelchair turning is easier if the knees are flexed rather than extended. Secondary hypotheses were that, with the knees flexed, overall wheelchair-user length decreases, the COM moves rearward, rolling and turning resistance decreases, traction increases and the moment of inertia decreases.

## METHODS

We studied 20 able-bodied subjects in a lightweight manually propelled wheelchair with rear-wheel drive and swivel casters. To test the two extremes of full knee extension and flexion, the front rigging of the wheelchair was removed. To determine the reliability of the measures, two trials were completed for each parameter tested. To test how angular velocity was affected by knee position, subjects were timed maximally rotating the wheelchair about the yaw axis, while keeping all four wheels within a 1.6m diameter circle. Immediately after, subjects quantified their subjective impression of the ease of turning using visual analog scales (VAS). To reflect how the magnitude of the turning circle was affected, the overall length of the subject and the wheelchair was measured. The reaction board method was used to determine how horizontal COM position changed, and a variation of the coast-down method (1) was used to measure rolling distance (an indirect and inverse measure of rolling resistance). We used a dynamometer to measure turning resistance (peak force needed to initiate yaw) and traction (peak force to initiate forward movement with rear brakes applied).

Modeling was completed to evaluate how moment of inertia is affected by changes in knee position. The user's moment of inertia was calculated using Dempster's cadaveric data for the 2.75th and 97.5th percentile male and female population (2,3). Knee-flexion angle was modeled from 0° to 120° in ten-degree increments, while all others segments remained static. The moment of inertia of the wheelchair used for empirical testing was determined using the torsional vibration method (4). It was assumed that the yaw axis was located between the rear wheel axles.

## RESULTS

The subjects' mean (SD) age, height, weight, sitting knee flexion and extension ranges were 21(0)years, 1.75(0.08)m, 68(12.2) kg, 135(6)°and 9(5)°. Correlation coefficients used to reflect test-retest reliability were high for most parameters ($r > 0.71$, $p < 0.007$), except for turning resistance. Matched-pairs t-tests, showed no significant differences between trials for any parameters.

Significant differences were found between knee flexion and knee extension for all parameters empirically tested ($p < 0.007$) (Figure 1). With the knees flexed, angular velocity was 40% faster, subjects' perceived exertion was 66% less, overall length was 39% shorter, COM was 38% closer to the rear wheel axles, rolling resistance was 21% lower, turning resistance was 17% lower, and rear-wheel traction was 12% greater. The small female model's total wheelchair-user system moment of inertia decreased 41.0%, the large female model's decreased 43.3%, the small male model's decreased 43.5%, and the large male model's decreased 38%.

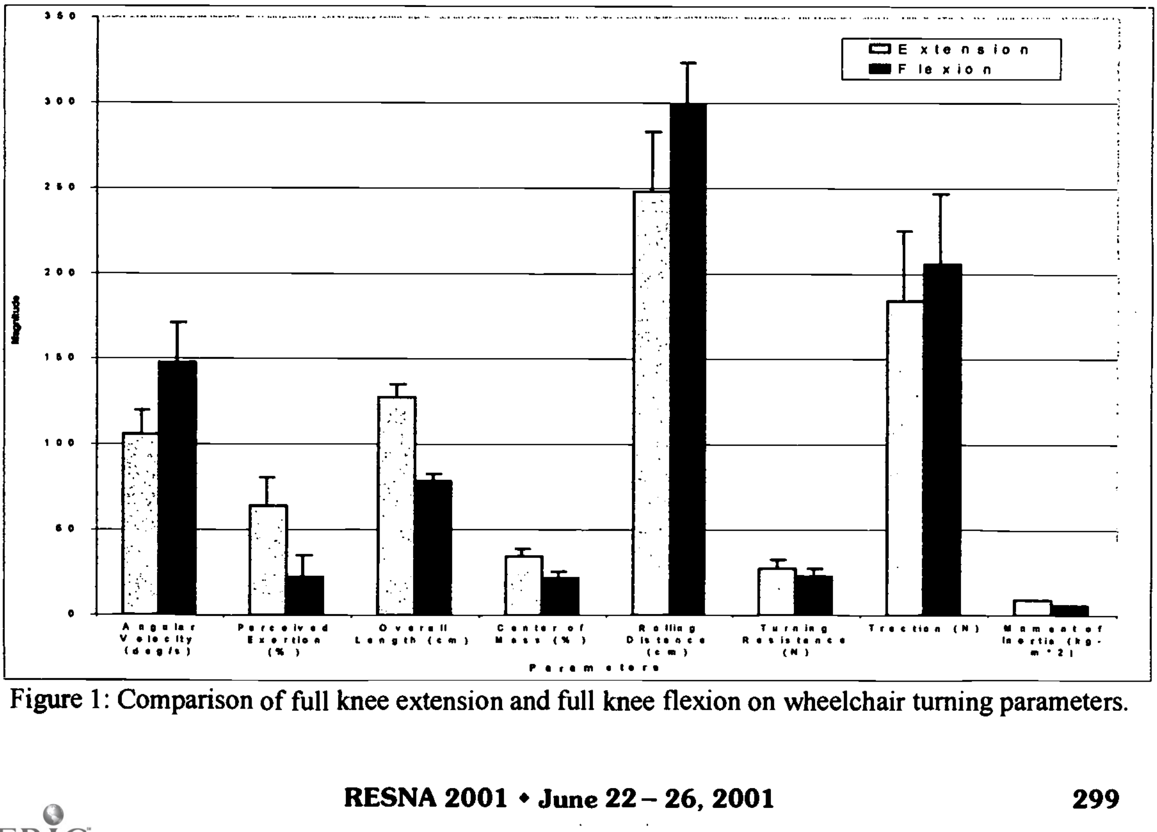


Figure 1: Comparison of full knee extension and full knee flexion on wheelchair turning parameters.

## DISCUSSION

All empirically tested hypotheses were corroborated. Increasing knee-flexion angle from full extension to full flexion increased the ease of turning to a clinically significant extent. Both the angular velocity and the perceived exertion (VAS) associated with the increased knee-flexion angle were affected. Several factors appeared to contribute to the increased ease of turning.

The largest contributing effect (38%) was seen in the horizontal position of the COM relative to the rear wheel axles. This effect most likely caused the effects seen in rolling resistance (21%), turning resistance (17%) and traction (12%) as decreased mass was distributed on the front casters. Although turning resistance appeared to be a significant contributing factor to the ease of turning, the low reliability of the method used decreased our confidence in the significance of the effect. The modeling results support the hypothesis that increased knee-flexion angles decrease the wheelchair-user system's moment of inertia about the yaw axis.

Limitations of this study include the size and type of sample used. Results using wheelchair users as subjects would be expected to vary from these findings due to differences in lower and upper extremity muscle mass. In addition, only one wheelchair was used and the front rigging was removed. Further research could examining how knee-flexion angle affects turning in various types of wheelchairs (with the front rigging in place), especially sport wheelchairs where rapid turning may be more common. The extreme positions tested also limit the clinical application of these results. Full flexion and extension are not as common as angles in between. The moment of inertia models provide some insight into the possible effect of these intermediate angles, suggesting that the relationship is a non-linear one. However, the generalizability of the results are limited as they are based on static rather than dynamic models.

Despite these limitations, the findings of this study have clinical implications. Specifically, wheelchair prescriptions may be altered to increase knee-flexion angle to increase the user's maneuverability. Furthermore, these findings support the evolution in wheelchair design towards wheelchairs with front rigging allowing for more than 90° of knee flexion.

## ACKNOWLEDGEMENTS

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# A MODEL-BASED APPROACH TO DETERMINE THE EFFECT OF HANDRIM COMPLIANCE ON PROPULSION EFFICIENCY

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## ABSTRACT

Manual wheelchair users are at risk of developing upper extremity injuries. A compliant handrim is a proposed technology that serves to reduce impact and peak forces during propulsion. Use of a compliant handrim was shown to reduce metabolic demand during propulsion, but the mechanism by which this occurs is not well understood. A dynamic wheelchair propulsion model was developed and used to study the effects of compliance on propulsion efficiency. The compliant handrim has two independent degrees of freedom, radial translation and rotation with respect to the wheel. The model predicted an increase in propulsion efficiency within an optimal compliance band. Results suggest that rotational compliance improves efficiency while translational compliance adversely affects efficiency. Future research will focus on validating and improving the model.

## BACKGROUND

It has been established that manual wheelchair users who push on the handrim with higher peak and impact forces during propulsion are more likely to develop an upper extremity injury (1). A compliant handrim is a standard handrim that is elastically rather than rigidly connected to the wheel, such that it can displace relative to the wheel when impacted by the hand. Compliant handrims are designed to reduce peak and impact forces during propulsion and therefore may be an effective injury-prevention mechanism. It was suspected that the use of a compliant handrim might increase metabolic demand during propulsion and therefore diminish its value as an injury-prevention mechanism. Oxygen consumption was measured during propulsion while using three different handrim prototypes of varying compliance. Metabolic demand was not found to increase and in fact decreased for two of the prototypes tested (2). It was hypothesized that the decrease in metabolic demand was due to either 1) the ability of the compliant handrim to store the kinetic energy from the arm during impact and to release it to the wheel, later in the push, or 2) the increased degrees of freedom of the handrim allowed the user to better optimize their propulsion stroke.

## RESEARCH QUESTION

The use of a compliant handrim was shown to reduce metabolic demand during propulsion for two prototype designs, yet the reason for this is not understood. How does handrim compliance reduce metabolic demand and how does varying the compliance characteristics affect this result?

## METHOD

A simplified dynamic wheelchair propulsion model was developed. The model is two dimensional, and is similar to propulsion on a dynamometer in that the wheelchair does not move forward but rather remains stationary as the rear wheel rolls. In the model, the mass of the rear wheel is modified such that the inertial characteristics of turning the wheel are equivalent to that of the wheelchair-user system rolling forward. The model consists of four rigid bodies: an upper arm, forearm-hand combination, handrim and wheel (Figure 1). The mass and geometric properties for the arm segments were based on anatomical measurements (3). The shoulder joint and the hub of the wheel are fixed in an inertial reference frame. The hand is constrained to the handrim by a penalty potential (very stiff springs). The handrim has two degrees of freedom with respect to the wheel. It can translate radially as well as rotate. Resistance to handrim displacement is provided by independent spring and damping elements for both degrees of freedom. Three external torques are applied to the system: a shoulder torque, an elbow torque and a resistive wheel torque. The shoulder and elbow torques are modulated such that they generate a prescribed force vector on the handrim. The resistive wheel torque used in the model was determined by a coast-down test (4).

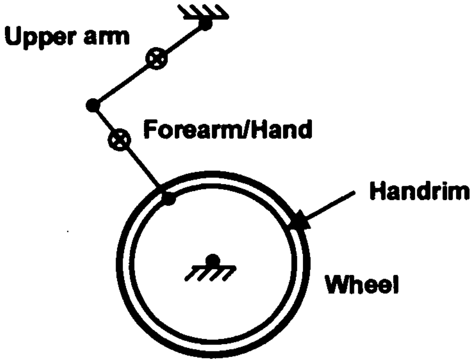


**Figure 1.** Wheelchair propulsion model

The penalty potential constraining the hand to the handrim is released during the push when the acceleration of the wheel decreases to zero. Propulsion efficiency is defined as the ratio of the output work to the input work for the cycle. The output work for the cycle is defined as the integral of the instantaneous output power over the cycle. The instantaneous output power is defined as the torque applied to the wheel multiplied by the angular velocity of the wheel. The input work is defined as the sum of the integrals of the elbow and shoulder joint torques verses time over the cycle, multiplied by a metabolic scaling factor. The metabolic scaling factor was determined such that the propulsion efficiency using a rigid handrim was similar to that which is commonly measured.

The model was evaluated for a 100-kg user with an initial propulsion speed of 0.75 m/s on a 2% incline. The prescribed force on the handrim was constant over the push with a value of 45 N in both the radial and tangential directions. The damping ratio was fixed at one half that of critically damped ($\zeta$ = 0.5). The compliance was varied 1) isotropically, such that both the radial and tangential compliance values were equal, 2) only in rotation, and 3) only in translation. The initial velocity of the arm at impact was 3 rad/s and 1 rad/s for the shoulder and elbow respectively. These initial conditions were modified such that the hand velocity matched that of the handrim to simulate propulsion without an impact.

## RESULTS

The metabolic efficiency predicted by the model for the isotropic compliance condition increases slightly followed by a dramatic decrease (Figure 2). The minimum compliance value represents a standard rigid handrim. The predicted effect of impacting the handrim on efficiency appears to be minimal (Figure 3). The degrees of the handrim are more influential on predicted efficiency (Figure 4), with purely rotational compliance improving efficiency and purely translational compliance reducing efficiency.

## DISCUSSION

The increase in propulsion efficiency measured when using a compliant handrim was unexpected. The model predicts this unexpected increase and indicates that such results are sensitive to the compliance characteristics. In particular, a critical value

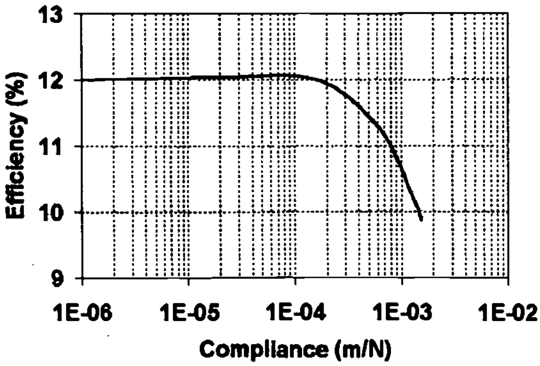


**Figure 2.** Predicted propulsion efficiency

exists for compliance, above which significant decreases in efficiency may occur.

The role of impact is slight but does agree with our expectations in that impact tends to increase efficiency. The role of the rotational and translational degrees of freedom appear to be of greatest consequence. Rotational compliance, having a positive effect, should be maximized, while translational compliance, having an adverse, effect should be minimized.

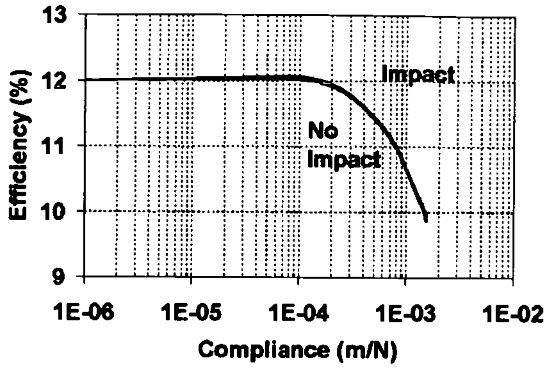


**Figure 3.** Effect of impact on efficiency

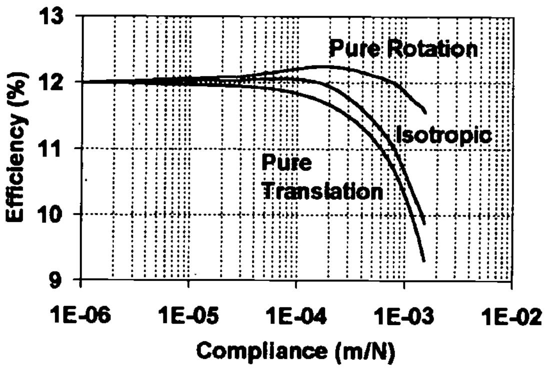


**Figure 4.** Effect of varying compliance characteristics on efficiency

The results of the model help to understand how compliance affects efficiency. Translational compliance reduces the moment arm of the tangential force with respect to the hub of the wheel, thus the same applied force results in a smaller moment applied to the wheel. Rotational compliance allows the arm to advance further along the angular path of the wheel, resulting in a more extended elbow at release of the handrim. As the elbow extends, the mechanical advantage of the arm increases thus requiring a smaller shoulder joint torque to create the same tangential force on the handrim.

Limitations of the model will be explored through a validation process in which model predictions will be compared to experimentally measured results. Potential improvements to the model include the force profile applied to the handrim, the addition of primary actuator muscles and the addition of a torso. Once validated, the model will be used to predict an optimal handrim compliance for a wide variety of conditions by varying the propulsion speed, degree of incline, user characteristics and wheelchair set-up.

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# PREDICTING SCAPULA ORIENTATION IN WHEELCHAIR PROPULSION

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## ABSTRACT

Descriptions of shoulder kinematics during wheelchair propulsion have mostly been based on motion of the upper arm due to the difficulty of measuring scapula movement *in-vivo*. Using a digitizing probe, the three-dimensional position of the scapula was recorded for 10 manual wheelchair users (MWUs) in five different statically held positions along the pushrim. Scapula and upper arm angles were computed for each position relative to the torso. A multiple regression analysis revealed that upper arm and torso angles are good predictors for estimating forward tipping, protraction and up/downward rotation of the scapula. Incorporating scapula kinematics into shoulder models may help identify specific biomechanical factors that lead to shoulder pathology.

## INTRODUCTION

The shoulder is clearly one of the most difficult joints to model due to its numerous degrees of freedom. What is commonly referred to as the "shoulder joint" actually consists of 4 joints: glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic. While the glenohumeral joint constitutes for a majority of the shoulder's overall range of motion, its movement is constrained by passive stabilizing structures like the glenoid labrum, joint capsule and ligaments as well as dynamic structures like the rotator cuff muscles. Complex biomechanical models can be used to determine the contributions of both active and passive structures to shoulder motion and power generation but it is difficult to apply the models in a dynamic activity such as wheelchair propulsion. A more detailed model requires many more input variables including scapula, clavicle and acromioclavicular joint kinematics as well as shoulder anthropometry often adopted from cadaver study. Unfortunately, accurately measuring the kinematics of each joint within the shoulder during wheelchair propulsion is impossible without the use of radiation technology such as fluoroscopy or an electromagnetic tracking device in which magnetic interference and receiver confusion are major concerns. Thus, in propulsion research, shoulder models have focused mainly on glenohumeral joint mechanics since upper arm motion can be easily recorded *in-vivo* via motion analysis systems, film, or video (1). However because they are simplified, they often only yield net joint forces and torques at the shoulder and provide no information regarding intrinsic forces.

Static measurements of the joints within the shoulder complex have been performed in light of the difficulty in capturing their movement patterns during an activity. Many researchers agree that there is a direct relationship between glenohumeral joint motion and scapulothoracic motion during arm elevation (2). If the orientation of the upper arm and thorax are known, then it may be possible to estimate the simultaneous scapula range of motion during propulsion so that more complex shoulder models can be used. Hence, this study aimed to derive a series of mean regression lines for 3D scapula orientation based on known positions of the humerus and torso in a simulated wheelchair push. Knowledge of scapula motion can help improve the shoulder models used in wheelchair propulsion research and aid in detecting injury mechanisms.

## METHODS

*Subjects*. Ten experienced MWUs consisting of 8 men and 2 women with a spinal cord injury (SCI) at the T-2 level or below provided informed consent to participate in this study. The average age, years with SCI, and mass were 40.7 ± 9.2 years, 16.9 ± 8.6 years, and 80.6 ± 13.7 kg, respectively.

*Experimental Protocol*: Subjects' were tested in their own personal wheelchairs and brakes were activated to prevent movement of the wheelchair. Since three subjects had significant right side shoulder involvement, the analysis was performed on the left side for all subjects. IRED markers of the *OPTOTRAK* motion analysis system (Northern Digital, Inc.) were secured to the following bony landmarks: acromion process, lateral epicondyle, and ulnar styloid. A rigid body made of carbon fiber composite with three non-collinear markers was attached to the sternum to measure torso rotation. A digitizer probe was designed and fabricated according to specification by Northern Digital (Figure 1). Six-markers were mounted, three on each side, to maximize their visibility by the two bilaterally placed *OPTOTRAK* cameras. Subjects were tested in five randomly presented hand positions: -30°,-15°, 0°, +15°, +30° with 0° at the top of the pushrim. At each angle, 3D positions of the arm and trunk markers relative to the global reference frame were recorded and the following three points on the scapula were digitized: angulus acromialis (AA); trigonum spinae (TS); and the angulus inferior (AI) (Figure 2). During the recordings no movements of the subjects were allowed.

Figure 1: Digitizing Probe

*Data Analysis*: Local coordinate systems (LCS) were constructed at the scapula (center at AA) (Figure 2), upper arm (center at acromion) (Figure 3) and torso. For the torso, the y-axis, Yt, pointed upward along the longitudinal axis of the sternum, the x-axis, Xt, perpendicular and anterior to the plane of the sternum, and the z-axis, Zt, perpendicular to Yt and Xt. The LCS defined the orientation of the torso, ${}^{G}R_{T}$, scapula, ${}^{G}R_{S}$ and upper arm, ${}^{G}R_{H}$ for each static position in relation to the global reference frame. The orientation of the scapula in any recorded position relative to the torso (${}^{T}R_{S}$) was then computed from the following:

$$ {}^{G}R_{T} \bullet {}^{T}R_{S} = {}^{G}R_{S} \quad \Longrightarrow \quad {}^{T}R_{S} = {}^{G}R_{T}' \bullet {}^{G}R_{S} $$

where $R'$ represents the transpose of a matrix. Upper arm orientation relative to the torso, ${}^{T}R_{H}$, was determined using a similar expression. The rotation matrices, ${}^{T}R_{S}$, and ${}^{T}R_{H}$ were comprised of three Euler angles. The rotation order was consistent with the International Shoulder Group's Standardized Protocol for measuring joint rotations (3). For the scapula, the first rotation ($S_y$) was around the Ys-axis and can be interpreted as pro/retraction. The second rotation ($S_x$) was around the Xs'-axis and represented up/downward rotation. The final rotation ($S_z$) was about the Zs''-axis and can be described as forward/rearward tipping. Thus, the resulting decomposition for a *YXZ* order of rotation was:

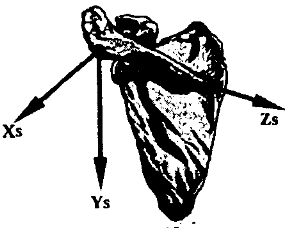


Figure 2: Scapula local coordinate system

Figure 2: Scapula local coordinate system

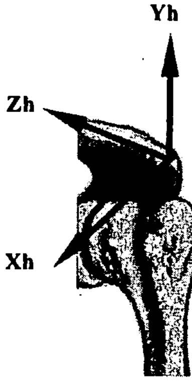


Figure 3: Shoulder local coordinate sys

$$ R = {}^{T}R_{S} = R(S_y) \bullet R(S_x) \bullet R(S_z). $$

The following equations were solved for the scapula rotation angles:

$$ S_y = a\tan\left(\frac{R(3,1)}{R(3,3)}\right); \quad S_x = a\tan\left(\frac{-R(2,3)}{\sqrt{R(1,3)^2 + R(3,3)^2}}\right); \quad S_z = a\tan\left(\frac{-R(2,1)}{R(2,2)}\right). $$

A *ZXY* rotation sequence was used for the upper arm matrix decomposition with the first rotation as flexion/extension ($H_z$), second rotation as abduction/adduction ($H_x$), and final rotation as internal/external rotation ($H_y$).

*Statistical Analysis*: The relationship between torso flexion, scapula, and upper arm orientation angles was tested across the group for all positions (N=50) using Pierson *r* correlations ($\alpha < 0.05$). All variables were entered into a stepwise multiple regression procedure using SPSS (SPSS, Inc.).

**RESULTS**

All three scapula angles were significantly related to the torso flexion angle, $T_z$ (Table 1). The up/downward rotation of the scapula, $S_x$, was also significantly related to both arm ab/adduction and flex/extension angles. In addition to the $T_z$, scapula tipping angle, $S_z$, was related to arm flex/extension angle. For both $S_x$ and $S_z$, 60% of the variation can be explained by the predictors. Although the regression results were also highly significant for $S_y$, only 30% of the variation can be explained by $T_z$. Interestingly, the int/external rotation angle although closely related to $S_y$, was not found to be a significant predictor for any of the scapula angles.

Table 1: Regression results for predicting scapula angles from torso flexion and arm angles. The coefficients of the lines, R value, and significance of the regression are shown. The general equation is: Angle=$a + b \bullet T_z + c \bullet H_x + d \bullet H_z$.

| *Angle* | *Constant* | $T_z$ | $H_x$ | $H_z$ | *R* | *SIG* |
|---|---|---|---|---|---|---|
| $S_x$ | -6.009 | -0.482 | 0.269 | 0.142 | 0.779 | .000 |
| $S_y$ | 13.512 | -0.277 | — | — | 0.531 | .000 |
| $S_z$ | 16.696 | 0.487 | — | -0.273 | 0.771 | .000 |

**DISCUSSION**

This study focused on deriving a means to estimate 3D scapula orientation from torso and upper arm orientation. Despite the variability among subjects in anthropometrics, wheelchair configuration, and positioning, for a simulated push, the ability to predict two of the three scapula angles appears to be very good. Veeger *et al.* who performed a similar study on four unimpaired male subjects using a standardized wheelchair found the int/external angle to be a predictor for $S_y$ and $S_x$ (4). In this study int/external rotation angles were found to vary largely between subjects and positions and thus were not significantly related to scapula orientation. The methods in both studies assumed rotational movement between the point-to-point positions but there was likely translational movement or sliding as well. Factoring this into the analysis may help to strengthen the relationships especially in predicting the pro/retraction angle. Presumably, if the scapula behaves similarly during wheelchair propulsion, then we can predict its orientation based on arm and torso motion which can be easily measured using common motion recording devices. Scapula kinematics can then be entered in as input parameters to the more sophisticated shoulder models to determine intrinsic forces. This information may be useful for identifying specific biomechanical predictors of shoulder pathology among MWUs.

**CONCLUSIONS**

Mean regression lines were derived for predicting 3D scapula orientation in a simulated push. Further investigation into improving the prediction power of the regression is warranted.

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# MECHANICAL ENERGY CHANGE WITHIN THE SEGMENTS OF UPPER EXTREMITY DURING WHEELCHAIR PROPULSION

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## Abstract

Understanding segmental energy and power may provide insight into injury mechanism during wheelchair propulsion. The purpose of this study was to investigate the segmental energy and power changes during wheelchair propulsion. Twenty-four wheelchair users were asked to propel their wheelchair at a constant velocity. The total energy and power of each segment was calculated from the kinematics data. Similar change patterns in energy and power were found within the three segments of upper extremity. The reason for these changes is explained.

## Introduction

Manual wheelchair propulsion is a strenuous process for most wheelchair users. Previous studies show that propelling a wheelchair may cause musculoskeletal injures to the upper extremity[1]. Since the upper extremity is critical in a manual wheelchair user's(MWU) daily life, these injures can lead to serious problems. Qualitative pattern of energy transfer has been reported to be useful in investigating different gaits between injured and non-injured individuals[2]. In order to understand complex propulsion movement and possibly reduce the risk of injures, it is important to gain insight into the segmental energy transfer during the propulsion.

Cerquiglini *et al.* and Veeger *et al.* reported that most external power for wheelchair propulsion was generated around the shoulder joint[3]. Recent, studies have focused on shoulder kinetics. However little information is available concerning the complete picture of upper extremity movement and coordination among the segments. The purpose of this study was to explore the energy transfer of each segment of upper extremity during propulsion and to determine whether there were general relationships between them.

## Method

*Subjects.* Twenty-four experienced MWUs with spinal cord injures at a T2-level or below gave informed consent to participate in this study. The sample consisted of 14 men and 10 women aged 34.0 ± 7.6 years. The average years post injury was 11.6 ± 5.5 years. All subjects reported to be free of pain and pressure sores at the time of this study.

*Test Protocol.* Kinematic data were collected by a three-dimensional camera system( OPTOTRAK, Northern Digital Inc.) at 60 Hz. IRED markers were placed on the subject's acromion process, lateral epicondyle, ulnar styloid, third Metacarpophalangeal (MP) joint and the wheelchair hub.

Each subject was asked to push their wheelchair at a constant speed of 0.9m/s(2mph). After reaching steady state, data was recorded for 20 seconds.

*Calculation of Segmental Energy Transfer.* The work-energy theorem enables two methods to calculate the net power supplied to the segment. One is to add up the segment's muscle and joint powers. The other is to calculate by taking the time derivative of the segment's total mechanical energy. The later one may be more accurate since the measures depend only upon kinematics and anthropometric data[4].

In this study, the segment's total mechanical energy was calculated from:

$$E(s,t_1) = m(s)\cdot g\cdot Y(s,t_1) + \tfrac{1}{2}\cdot m(s)\cdot[V(s,t_1)]^2 + \tfrac{1}{2}\cdot I(s)\cdot[\omega(s,t_1)]^2 \qquad (1)$$

Where $m(s)$ and $I(s)$ are its mass and moment of inertia about a medio-lateral axis through center of gravity. $Y(s,t_1)$ is the height of its center of mass at time $t_1$ and $V(s,t_1)$, $\omega(s,t_1)$ are its linear and angular velocity at time $t_1$. The net power was calculated by the finite difference equation as follows:

$$P(s,t_1) = \dot{E}(s,t_1) = [E(s,t_2) - E(s,t_0)]/2\Delta t \qquad (2)$$

Where $t_0$, $t_1$, $t_2$ represent different times separated by the sampling interval of camera system. All calculations were implemented in MATLAB.

## Results

Typical patterns of segmental energy and power changes are shown in figures 1-3. Each graph represents a complete cycle. The propulsion phase generally occurs between 0 and 30 units on the time axis. The unit for the time is 1/60$^{th}$ second. Table 1 lists the average and peak values of total energy and power for each segment for all 24 subjects.

All three segments show energy and power changes similarly. The segmental energy begins to increase shortly after the stroke beginning and reaches its first peak by mid-stroke. At the end of stroke, segmental energy reaches its base level. The secondary energy peak occurs at middle of the recovery phase. The positive segmental power implies a net increase in potential and/or kinetic energy. Conversely, negative means decrease in total segmental energy. The shape of power curves look similar to its corresponding energy curve, with exception that peak values and base levels occur at earlier time.

**Table 1- Peak and Mean Values of Segmental Energy and Power during Propulsion (n=24)**

| | Segmental Energy (J) | | Segmental Power (W) | |
|---|---|---|---|---|
| | Peak value | Mean value | Peak value | Mean value |
| Upper arm | 18.228 (5.810) | 17.633 (5.325) | 5.003 (1.358) | 0.045 (0.091) |
| Forearm | 6.893 (2.054) | 6.332 (1.913) | 5.295 (2.160) | 0.043 (0.082) |
| Hand | 2.340 (0.471) | 2.071 (0.387) | 2.793 (1.198) | 0.014 (0.046) |

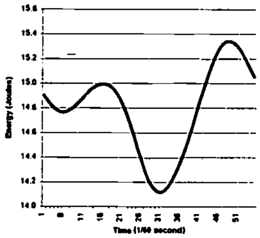
Fig 1(a) Total Energy of Upper arm

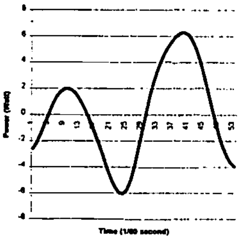
Fig 1(b) Power of Upper arm

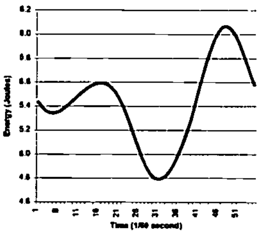
Fig 2(a) Total Energy of Forearm

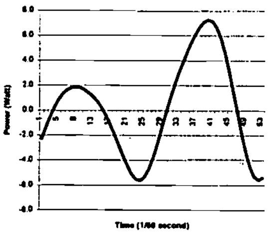
Fig 2(b) Power of Forearm

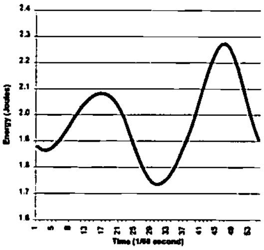
Fig 3(a) Total Energy of Hand

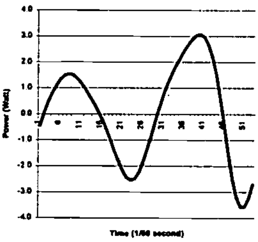
Fig 3(b) Power of Hand

## Discussion

The first energy peak occurs as the subject accelerates to push the wheelchair in mid-stroke. The energy increase of the three segments is initially generated by the shoulder flexors. After mid-stroke, the subject tends to decelerate push speed and totally stops for a short period of time at the end of stroke. So total energy decreases and reaches the baseline at the end of stroke. After the hand is off the pushrim, the subject begins to pull the entire upper extremity back. This increases total mechanical energy and results in the secondary peak at the middle of the recovery phase.

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# THE EFFECT OF A WHEELCHAIR INTEGRATED OCCUPANT RESTRAINT SYSTEM ON WHEELCHAIR TIE-DOWN AND OCCUPANT RESTRAINT DESIGN CHARACTERISTICS

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## ABSTRACT

Wheelchair occupant restraint systems (WORS) are commonly installed in motor vehicles for individuals who do not transfer from their wheelchair into a motor vehicle seat when using transport. WORS existing of upper torso and/or pelvic belts are usually installed fixed to the motor vehicle structure according to SAE J2249 belt fit criteria for a 50$^{th}$ percentile male occupant. However, when a fixed vehicle mounted wheelchair occupant restraint system (FWORS) is used to secure various sized wheelchair occupants, belt fit may be compromised resulting in user discomfort and unsafe conditions during motor vehicle impact. In this study a comparison was made between a FWORS and a wheelchair integrated occupant restraint system (WIRS). Belt loads of both restraint scenarios were measured during a 20g/30mph sled impact test of a wheelchair and seated Hybrid III test dummy secured with one of the occupant restraint scenarios. Results from the sled impact test showed higher wheelchair rear tie-down loads and lower upper torso and pelvic restraint loads for the WIRS scenario. The use of such a 'customized' WIRS could potentially decrease wheelchair occupant risk of injury and improve user comfort when compared to WORS, which are fixed to the motor vehicle.

## BACKGROUND

At the present time individuals using wheelchairs as motor vehicle seats often use WORS, which are fixed to the motor vehicle structure. A study focusing on the safety of wheelchair occupant restraint systems has shown that the location of the upper torso belt anchor point influences wheelchair occupant crash protection [1, 2]. A previous study showed compromised belt fit when using a fixed vehicle-mounted WORS for 50$^{th}$ percentile male users, 5$^{th}$ percentile female users and six year old children [3]. Other research demonstrated that upper torso and pelvic belts installed in para-transit, public-transit and private vehicles may not be comfortable and are difficult to use [4, 5]. A case was made for integrated restraints, when comparing injury criteria of a fixed vehicle-mounted and a wheelchair integrated restraint scenario using computer simulation [6]. Much research has been done in the automotive industry on the benefits of seat integrated occupant restraint systems [7, 8]. When implementing this restraint technology in the wheelchair industry similar improvements can be expected in frequency of belt usage, safety, user comfort and usability. The American National Standards Institute (ANSI)/ Rehabilitation Engineering Society of North America (RESNA) Vol.1 part 19, Wheelchairs used as Seats in Motor Vehicles, standard (WC-19) promotes occupant safety for motor vehicle occupants who remain seated in their wheelchair during transit [9]. This voluntary standard requires that a wheelchair designed for use in transportation be dynamically tested (20g/30mph sled impact test) with a wheelchair-anchored pelvic belt (2-year phase in period, starting April, 2000).

## RESEARCH QUESTION

What is the difference in wheelchair tie-down and occupant restraint (WTORS) loads when using a FWORS versus a WIRS scenario?

## METHOD

A commonly available wheelchair seating system (WCSS) (Tarsys, Invacare, Ohio) was mounted to a surrogate wheelchair base resembling a power base wheelchair. A 180 lb. Hybrid III ATD representing a 50$^{th}$ percentile male occupant, was positioned on the WCSS and restrained according the Society of Automotive Engineers (SAE) J2249 guidelines for belt angles and restraint anchor locations [10]. The WCSS and base system were secured a four-point strap type tie-down system with rear securement points at the height of the systems' center of gravity. The upper torso and pelvic restraints and the rear tie-down straps were instrumented with webbing tension load cells to measure load during impact. A 20g/30mph sled impact was conducted with the following two restraint scenarios:

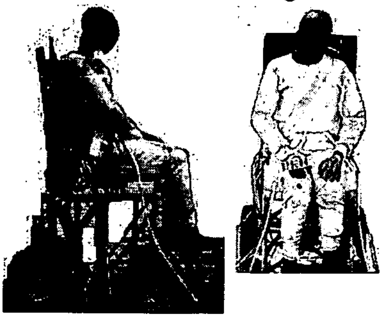

*Figure 1: Test setup of WIRS scenario*

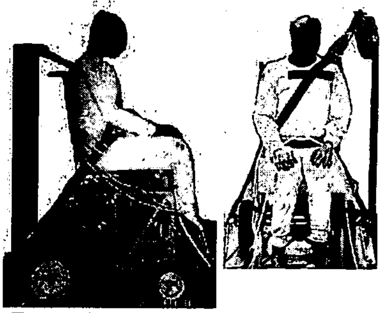

*Figure 2: Test setup of FWORS scenario*

1. WIRS (see Fig. 1): A WCSS was reinforced with a rigid structure to withstand the impact load that acts on the upper part of the seat back during impact. The upper torso restraint and pelvic anchors were mounted to the WCSS structure. The weight of the wheelchair and seating system is 210 lb.
2. FWORS (see Fig. 2): The upper torso restraint anchor was attached to a rigid pedestal simulating the vehicle structure. The upper torso belt was attached to the pelvic belt via a pelvic belt-mounted fitting. The pelvic restraint anchors were attached to the impact sled. The weight of the wheelchair and seating system was 180 lb.

Occupant restraint loads and wheelchair tie-down loads were recorded during the sled impact tests using webbing tension load cells connected to the upper torso restraint, pelvic restraint and rear wheelchair tie-down straps. The ATD was equipped with a linear potentiometer at the sternum to collect compression data.

Results

Figures 3, 5 and 6 show respectively the force-time history of the upper torso restraint, the maximum (right) pelvic restraint and the left and right rear wheelchair tie-down straps for the FWORS and the WIRS scenarios. WIRS peak upper torso restraint load is also delayed as compared to the FWORS scenario. Figure 4 shows the ATD sternum compression for both restraint scenarios.

**DISCUSSION AND CONCLUSION**

Ongoing research on satisfaction and use of wheelchair occupant restraints in public and private vehicles showed a low rate of use of FWORS systems in transit vehicles when compared to (custom) private vehicles. This study satisfaction study promotes the fact that a WIRS may be better suited to safely secure various wheelchair occupants and wheelchair types, it may increase restraint usage, improve belt fit and decreases occupant risk of injury in case of motor vehicle impact. When comparing both restraint scenarios, the WIRS showed higher wheelchair tie-down loads. Factors that may influence this are the higher weight of the WIRS adapted to the seating system and the added weight of the wheelchair occupant carried by the tie-down system. Upper torso restraint loads were lower for the WIRS scenario causing a decrease in sternum compression. Other factors influencing sternum compression are seat back stiffness of the WIRS scenario allowing energy absorption during impact. Wheelchairs equipped with a WIRS will require tie-down straps of higher strength as well as higher strength wheelchair-mounted upper torso and pelvic restraint anchorages. Manufacturers of both tie-downs and wheelchairs incorporating integrated restraints must be aware of thie key point of more stringent design requirements in the development of their transport safe products. Further research is underway exploring additional restraint characteristics of the WIRS and their effect on occupant risk of injury.

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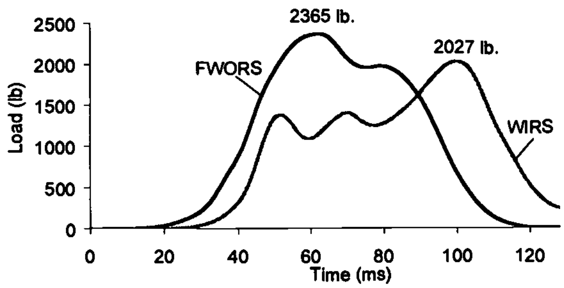


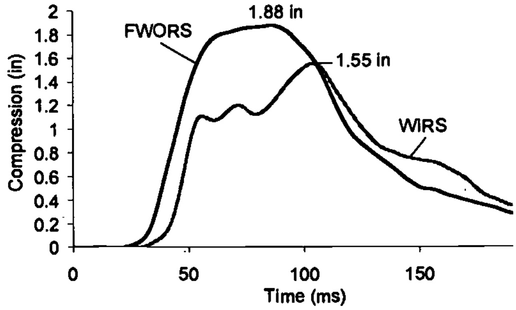
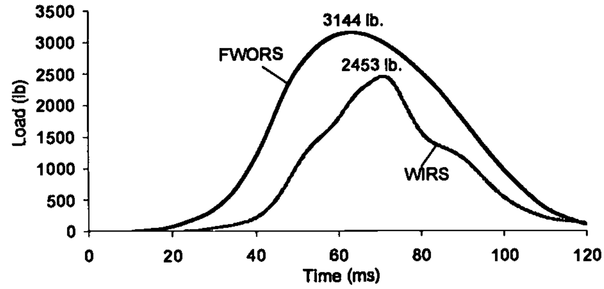




*Figure 3 (left): Upper torso restraint load history for the WIRS and FWORS scenarios*
*Figure 4 (right): Mid-sternum compression for the WIRS and FWORS scenarios*



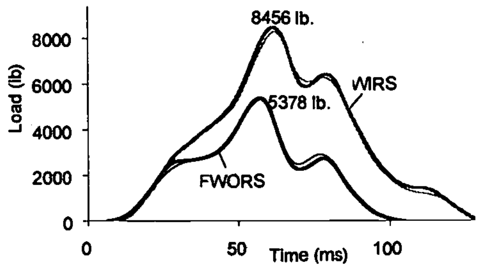




*Figure 5 (center): Maximum pelvic restraint loads for the WIRS and FWORS scenarios*
*Figure 6 (right): Rear wheelchair tie-down load for the FWORS and WIRS scenarios*

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## USABILITY AND SATISFACTION OF WHEELCHAIR OCCUPANT RESTRAINT SYSTEMS USED DURING MOTOR VEHICLE TRANSPORT

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### ABSTRACT

Individuals using wheelchairs in motor vehicles often use their wheelchairs as motor vehicle seats. In this study the usability and satisfaction of currently used wheelchair occupant restraint systems (WORS) was evaluated. A group of 31 individuals using wheelchairs were surveyed about the usability and comfort of WORS installed in para-transit, mass-transit and private vehicles. Results from the survey showed that individuals using upper torso and pelvic restraints installed in their private vehicle experience the use of WORS to be quick, easy and comfortable. However, WORS installed in mass-transit and para-transit are often difficult to reach, time consuming to use and uncomfortable to wear due to poor belt fit. Cause of poor belt fit is due to various types of wheeled mobility devices and various sized individuals using a WORS that is mounted in a fixed location to the vehicle structure. This study documents the need for an occupant restraint system solution that is safer, more comfortable, and easier to use independently for a variety of wheelchairs and occupants sizes traveling with para-transit and mass-transit vehicles.

### BACKGROUND

For individuals who do not transfer from their wheelchair into a motor vehicle seat often the wheelchair functions as a motor vehicle seat. Strap type tie-down systems are commonly used to secure the wheelchair to the motor vehicle during transport. Belt type occupant restraints, mounted to the vehicle structure are currently used to secure individuals within their wheelchairs. They exist of upper torso and pelvic restraints preventing the wheelchair occupant from impacting the vehicle interior during motor vehicle impact. The National Highway Traffic Safety Administration (NHTSA) reports that in 1996, more than 60 percent of motor vehicle occupants killed in fatal crashes were unrestrained. Results from a survey among a group of wheelchair users with spinal cord injury concerning the use of safety equipment such as wheelchair tie-downs and occupant restraints [1] showed that only 50% of the individuals traveling in privately owned vehicles use occupant restraints. A group of 74 individuals using their wheelchair as a motor vehicle seat reported difficulties with wheelchair securement systems as well as occupant restraint systems in motor vehicles [2].

### RESEARCH OBJECTIVE

This study is a preliminary effort to obtain information about occupant restraint usage and satisfaction of individuals using wheelchairs in different types of motor vehicle transport.

### METHOD

A survey was developed and distributed through the World Wide Web and through the Committee for Accessible Transportation of a para-transit provider. Table 1 shows the survey questions. 31 wheelchair occupants participated in the study. All respondents used their wheeled mobility device as a motor vehicle seat while traveling in motor vehicles (IRB#990680-9906). The responses to the survey remained anonymous.

*Table 1: Survey questions to collect information regarding the usability and comfort of currently used occupant restraint systems.*

| | |
|---|---|
| 1. | Do you use your wheelchair as a motor vehicle (MV) seat when using transportation? Yes/No |
| 2. | What type of transportation do you use? Para-transit/Mass-transit/Private vehicle/Other |
| 3. | Do you use besides a wheelchair restraint any form of occupant restraint? Yes/No/Positioning belt on wheelchair |
| 4. | What type of occupant restraint do you commonly use? None/Lap belt/Shoulder belt/Lap and shoulder belt/None |
| 5. | Is the lap belt you use fixed to the MV? Yes/No, fixed to wheelchair/ Don't know/None available/Don't use any |
| 6. | Is the shoulder belt fixed to the MV? Yes/No, fixed to wheelchair/ Don't know/None available/Don't use any |
| 7. | Did you ever choose not to wear a restraint? Yes,/No, I wear a lap belt/No, I wear a shoulder belt/No, I wear both |
| 8. | Do you need help restraining yourself with the lap or shoulder belt? Yes, because/No/Sometimes, when... |

9. Does it take a long time to 'buckle up'? Yes, ...min/No, because/I don't know/ I don't use any
10. Does the restraint fit you well? Yes/No/I don't know/I don't use any
11. Does the restraint feel comfortable? Yes/No/I don't know/I don't use any
12. Is the restraint easy to use? Yes/No, because:/I don't know/I don't use any

## RESULTS

Table 2 lists the findings from the completed surveys. Several individuals completed additional surveys for the different types of motor vehicles they used for transportation. The total number of completed surveys was 43. The results from the observation and the survey give a perspective on the perceived usability, satisfaction, comfort and fit of currently installed occupant restraint systems for wheelchair users in the common types of wheelchair transportation vehicles.

*Table 2: Survey results for para-transit, mass-transit and private vehicles*

| Interpretations | Para transit | Mass-transit | Private vehicle | Other vehicle types |
|---|---|---|---|---|
| No. of surveys | 16 | 11 | 14 | 2 |
| Subjects using WORS | 13 | 7 | 11 | 1 |
| Subjects only using their positioning belt | 0 | 9 | 3 | 0 |
| Subjects only using a pelvic belt | 3 | 1 | 3 | 0 |
| Subjects only using an upper torso belt | 0 | 0 | 2 | 0 |
| Subjects using both the upper torso and pelvic belt | 10 | 3 | 8 | 0 |
| Subjects using no form of WORS | 2 | 4 | 1 | 1 |
| Number of WORS that are fixed to the vehicle | 4 | 1 | 10 | 0 |
| Subjects who choose not to wear (part of) a WORS | 9 | 11 | 5 | 2 |
| Number of subjects needed assistance with WORS | 13 | 11 | 6 | 1 |
| Number of subjects using WORS independently | 2 | 0 | 8 | 1 |
| The WORS is time consuming to use | 9 | 6 | 3 | 1 |
| The WORS is quick to use | 7 | 1 | 10 | 1 |
| The WORS has a good belt fit | 7 | 4 | 9 | 1 |
| The WORS has a poor belt fit | 8 | 3 | 3 | 1 |
| The WORS is comfortable | 6 | 3 | 10 | 1 |
| The WORS is not comfortable | 9 | 4 | 1 | 1 |
| The WORS is easy to use | 13 | 6 | 10 | 2 |
| The WORS is hard to use | 3 | 3 | 2 | 0 |

## DISCUSSION AND CONCLUSION

Wheelchairs in para-transit vehicles are required to be secured by the driver, but the use of a WORS is on a voluntary basis. The usage of fixed vehicle mounted occupant restraint systems (FWORS) was found to be rather time consuming and uncomfortable in this type of motor vehicle. Wheelchair occupants traveling with mass-transit vehicles use their positioning belt for stability during transport more than they do the FWORS provided in these types of vehicles. However, positioning (postural) belts are not appropriate substitutes for crashworthy occupant restraints. Individuals using mass-transit vehicles seem to choose not to wear the provided WORS because of their need for assistance and the amount of restrain time it consumes. In private vehicles, upper torso and pelvic belts fixed to the motor vehicle are generally easy to use, independent to use, comfortable and provide the occupant with a good belt fit. Comments of wheelchair users on the survey questions indicated less than adequate comfort, satisfaction, belt fit, and ease of use when rating WORS currently installed in para-transit and mass-transit vehicles.

The Society of Automotive Engineers (SAE) J2249 and the ANSI/RESNA WC-19 standard include requirements for proper belt fit and recommend belt angles and anchorage locations for the pelvic and upper torso restraints [3]. A study focusing on the usability and safety of WORS has shown that the location of the upper torso restraint anchor point influences wheelchair occupant crash protection [4, 5]. Much research has been done in the automotive industry on the benefits of seat-integrated occupant restraint systems, which provide a more customized belt fit [6-9]. When implementing this restraint technology in the wheelchair industry similar improvements can be expected in frequency of belt usage, safety, user comfort and usability. Integrating the upper torso and pelvic belt on the wheelchair frame can increase seat belt use, improve safety, comfort and ease of use of upper torso and pelvic belts [10, 11]. The ANSI/RESNA WC 19, Wheelchairs used as Seats in Motor Vehicles, promotes occupant safety for motor vehicle occupants who remain seated in their wheelchair during transit [12]. This voluntary standard requires that a wheelchair designed for use in transportation be dynamically tested (20g/30mph sled impact test) with a wheelchair-anchored pelvic belt (2-year phase in period starting April, 2000). Results from this survey support the WC 19 requirement for on-board pelvic belts, and further suggests the need for integrated on-board shoulder belts. Such integrated restraint options on wheelchairs will likely improve safety, comfort and ease of use over currently available WORS.

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# EVALUATION OF WHEELCHAIR SLING SEAT AND SLING BACK CRASHWORTHINESS

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## ABSTRACT

Many wheelchairs are used as vehicle seats by those who cannot transfer to a vehicle seat. Although ANSI/RESNA WC-19 has been recently adopted as a standard to evaluate crashworthiness of the wheelchairs used as motor vehicle seats, replacement or after-market seats may not be tested to this standard. This study evaluated the crashworthiness of two specimens each of three sling backs and three sling seats using a static test procedure intended to simulate crash loading conditions. All, but two back specimens and two seat specimens withstood the test criterion load. Failures occurred at the seams of the side openings of upholsteries, where the wheelchair frame inserts for attachment.

## BACKGROUND

Wheelchair users who cannot transfer to vehicle seats remain in their wheelchairs using them as vehicle seats while they travel. However, since wheelchairs are primarily designed to provide mobility for individuals and not designed as vehicle seats, wheelchair seats, backs, components, and frame structures may not be able to withstand the high loads that can occur during crashes. ANSI/RESNA WC-19 *Wheelchairs Used as Motor Vehicle Seats*, which has been recently adopted as a standard, evaluates crashworthiness of wheelchairs used as seats in motor vehicles (1). Despite an effort by the ANSI/RESNA WC-19 standard to evaluate wheelchair crashworthiness, replacement or after-market seats may not be tested to this standard. Evaluation of wheelchair seating system (WCSS) crashworthiness independent of the wheechair frame is important when attempting to provide a level of occupant protection equal to that of automotive seats during impact. This study proposes a static test method to evaluate two specimens of three unique sling backs and three unique sling seats that are commercially available: E&J P2 Plus, Invacare 9000XT, and Sunrise Medical Quickie.

## RESEARCH QUESTION

Do commercially available wheelchair sling seats and sling backs withstand loads that may be encountered in a motor vehicle crash?

## METHODS

### Development of Test Criteria Loads

In developing test criterion loads for the sling seats, the computer crash simulation studies done by Bertocci et al. and limited sled impact tests were reviewed to determine seat loads (2). The seat force associated with a 20g/30mph frontal impact with 50$^{th}$ percentile male Hybrid III test dummy was found to be approximately 3750 lb.

Sling backs may be exposed to two loading conditions during impacts: loads encountered during rear impacts and rebound loads associated with frontal impacts. Rear impact loads were derived from FMVSS 207 test criterion, which applies a 20g static load to the seat back portion of seating systems (3): rear impact loading was calculated as 20 x (weight of the upper torso of a 50$^{th}$ percentile male + weight of each wheelchair sling back). The equivalent calculated rear impact load of each sling back was approximately 2280 lb. Rebound loads associated with frontal impact were determined from computer crash simulations. Peak back support loading associated with rebound of a 50$^{th}$ percentile male was found to be approximately 2290 lb. In developing test criterion loads for the sling backs, the worse case loading scenario (2290 lb) was chosen.

To successfully meet test criteria in this study, sling backs are required to withstand a **2290 lb** load, and sling seats should be capable of withstanding **3750 lb** load. Both seats and backs must also be able to withstand the test load for 5 seconds.

<u>Test Set Up</u>

Figure 1 and Figure 2 show the test set ups for sling seat and sling back tests. A rigid test fixture simulating a common adult wheelchair seat or back frame was developed to mount the sling seat or back specimens. To apply a distributed load to the sling upholsteries, a back unit and a seat unit of the ISO 7176-07 test dummy were used (4). The test was executed as follows:

1. A sling seat or a sling back was mounted to the rods of the test fixture.
2. The seat unit or the back unit of the ISO test dummy was placed on top of the sling upholstery to be tested.
3. A vertical downward load was applied using Instron Series 4200 loading machine at the center of gravity of the test dummy.


*Figure 1 Sling Back Test Set Up*

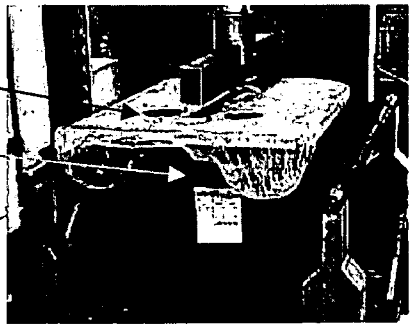


*Figure 2 Sling Seat Test Set Up*

The load was applied at a 20 in/min Instron machine cross head speed, held for 5 seconds at the target load and release at 20 in/min. Instron cross head position and the applied load were recorded during the test.

## RESULTS

Table 1 shows the achieved forces of the tested sling upholsteries. Although the 2nd specimen of the P2 Plus sling seat withstood the target force, the 1st failed at a high load of 3123 lb. due to the failure of seat reinforcement bar (see Figure 3). The 1st specimen of the Invacare 9000XT sling seat withstood the target force, but the 2nd failed to pass the test criterion, which requires holding the target load for 5 seconds. Once it reached the 3790 lb. force, one side of the upholstery failed (see Figure 4). Both Sunrise Medical Quickie sling seat specimens withstood the target force.

Results of the sling back tests show that the Invacare XT and Sunrise Medical Quickie backs withstood loads higher than the test criterion load, but both E&J P2 Plus specimens failed before reaching the target load. As shown in Figure 5, failure of both P2 Plus specimens occurred at the seams of the side openings. Two specimens of each sling upholstery showed similar load versus deflection characteristics. (See Figure 6 and Figure 7)

Table 1 Results of the Sling Back Test

| Tested Sling Upholstery | Sling Seat Achieved Force, (lb) | | Sling Back Achieved Force, (lb) | |
|---|---|---|---|---|
| | 1st Specimen | 2nd Specimen | 1st Specimen | 2nd Specimen |
| E&J - P2 Plus | 3123 | 3846 | 1567 | 1787 |
| Invacare - 9000XT | 3846 | 3790 | 2368 | 2358 |
| Sunrise Medical - Quickie | 3851 | 3846 | 2341 | 2385 |

*Figure 3 Failure of E&J P2Plus Sling Seat Reinforcement Bar*

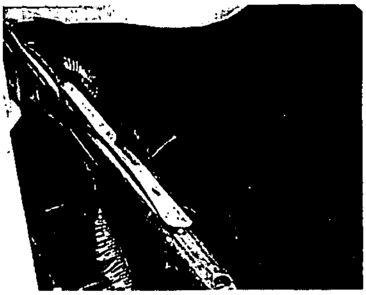

*Figure 4 Failure of Invacare 9000XT Sling Seat*

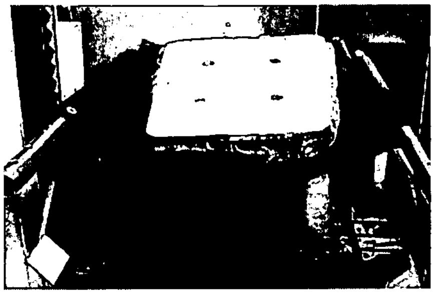

*Figure 5. Failure of E&J P2Plus Sling Back*

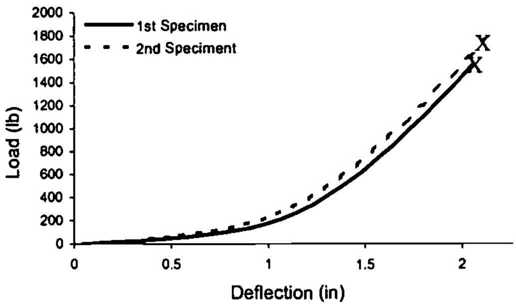


*Figure 6 Load vs. Deflection Curve for E&J P2 Plus Sling Back - "X" indicates failure*

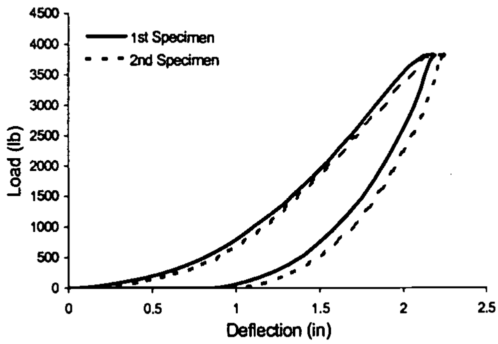


*Figure 7 Load vs. Deflection Curve for Sunrise Medical Quickie Sling Seat*

## CONCLUSIONS

Two specimens of three sling backs and three sling seats were evaluated using a static test method. All, but two sling back specimens and two sling seat specimens, withstood the test criterion load. Failure occurred at upholstery seams and side opening reinforcement bars. Manufacturers should consider reinforcing or strengthening stitch patterns when sling upholsteries are intended for use in transport. This study provides a preliminary screening of commonly used wheelchair sling upholsteries crashworthiness. In the future, additional dynamic testing is needed to validate the static test protocol proposed in this study.

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# DEVELOPMENT OF A STATIC TEST METHOD TO EVALUATE CRASHWORTHINESS OF WHEELCHAIR SEATING SYSTEMS USED AS MOTOR VEHICLE SEATS

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## ABSTRACT

A static test method was developed based upon FMVSS 207, limited 20g/30mph sled testing and computer crash simulations in order to evaluate crashworthiness of an after-market or add-on wheelchair seating systems (WCSSs). The rigid test wheelchair (WC) frame, surrogate attachment hardware, surrogate support surface, and reference loader gauges were designed and fabricated for the study. Two sets of forty different WC seating components were evaluated. Similar failure modes observed during previously conducted sled impact were observed in the static tests of some of the products. This test method provides a means for evaluating WCSS independent of a specific frame and provides a preliminary screening of crashworthiness.

## BACKGROUND

Since the Americans with Disabilities Act was enacted, more WC users rely on public transportation. Many remain in their WCs when they travel. Moreover, many individuals with disabilities modify motor vehicles in order to drive in their WCs. Since WCs have not typically been designed to be used as vehicle seats, WC seats, backs, components, and frame structures may not be able to withstand the high loads that can occur during crashes.

## STATEMENT OF THE PROBLEM

ANSI/RESNA WC-19 has been recently adopted as a standard to evaluate crashworthiness of WCs used as seats in motor vehicles. A dynamic test in the standard requires that a complete WC be sled impact tested using a 20g/30mph frontal crash pulse (1). However, substitute, replacement or optional seating systems are often added as after-market products, and will not have been sled tested. It is typically not possible to evaluate the whole WC, including seating systems, for those seating systems that are provided as replacement products after the WC has been in the field. In these after-market cases, evaluation of the performance of an individual seating system independent of a specific WC frame may be crucial to WC user safety.

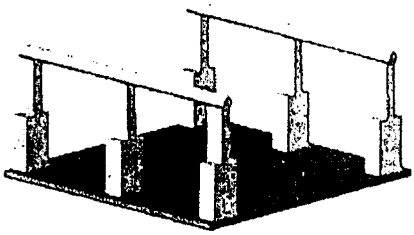

*Figure 1 Test Fixture*

## RATIONALE

A test method that can evaluate individual seating systems independent of the WC frame upon which it may be mounted is needed to address after-market seating. The objective of this study was to develop a low cost static test method that can be used to evaluate crashworthiness of WCSSs independent of a specific WC frame.

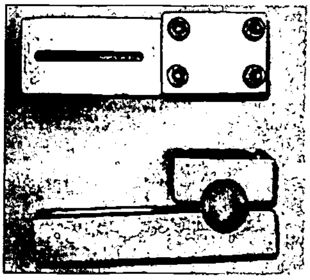

*Figure 2 Surrogate Attachment Hardware*

## DESIGN AND DEVELOPMENT

### Development of Test Criteria Loads

<u>Seat Backs and Back Attachment Hardware:</u>

In developing test criterion for WCSS back surfaces and back attachment hardware, two loading conditions were considered: Rebound loads associated with frontal impacts, and loads encountered during rear impacts.

Rear impact loads were derived following Federal Motor Vehicle Safety Standards (FMVSS) No. 207 test criterion (2). Although FMVSS 207 utilizes the weight of the seat back times 20 to derive the applied static test load, it is more representative of crash loading conditions to utilize the sum of the upper torso and seat back weights times 20. Accordingly, rear impact loading was calculated as 20 x (weight of the upper torso of a 50th percentile male + weight of each WC seat back) = 20 x (113 lb + $WT_{wc\text{-}back}$).

The maximum rebound load associated with frontal impact was estimated from a previously validated 20g/30mph frontal impact computer crash simulation (3). The peak seat back loading associated with rebound of a 50th percentile male was found to be 2290 lb.

For each WC back seating system, the worse case loading scenario between two loading conditions (rear impact vs. rebound) was chosen as test criterion load.

<u>Seats and Seat Attachment Hardware:</u>

In developing test criterion for WCSS seat surfaces and seat attachment hardware, loads were determined from a computer crash simulation study done by Bertocci et al. (3). Consistent with ANSI/RESNA WC-19, the computer simulation used a 50th percentile male Hybrid III test dummy. The maximum seat force associated with a 20g/30mph frontal impact was found to be approximately 3750 lb.

**Test Apparatus**

A rigid test fixture representing a common adult WC frame was fabricated in order to mount the WCSS specimens. Two 1" diameter solid rods spaced 18" apart simulated the WC frame (see Figure 1). To test the WCSSs supplied without attachment hardware, aluminum surrogate hardware was fabricated (see Figure 2). A surrogate seat/back surface was fabricated to test seat and back attachment hardware. It is 18" * 18" to represent a standard WC seat or back support surface (see Figure 3). The bottom and back units of the ISO 7176-07 reference loader gauge (RLG), which was "designed to simulate the dimensions and mass distribution of the human body", were developed and used to apply a distributed load to the WCSS (4). The bottom unit represents the buttocks and thighs, and the back unit represents the upper torso of a 50th percentile male (see Figure 4 and Figure 5).

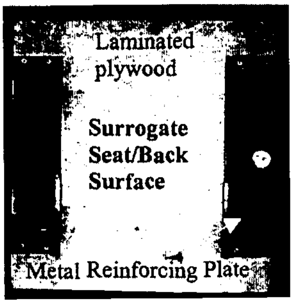


*Figure 3*
*Surrogate Plate*

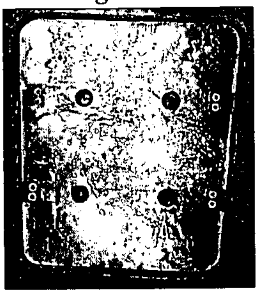

*Figure 4*
*Back Unit of ISO RLG*

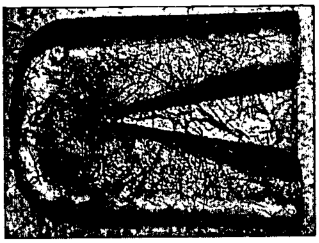

*Figure 5*
*Bottom Unit of ISO RLG*

**Test Set Up** (See Figure 6)

WCSS specimens were tested according to the following steps:

1. Mount the rigid test fixture to Instron loading machine.
2. Attach WCSS specimen to the test fixture with either manufacture-provided attachment hardware or surrogate hardware.

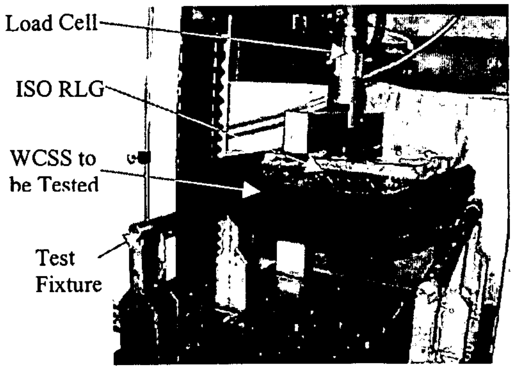


*Figure 6 Test Set Up*

3. Place the back unit/bottom unit of the RLG on the back/seat support surface to be tested.
4. Apply the test criterion load (an Instron crosshead rate of 20 in/min) to the back unit/bottom unit of the RLG through the center of gravity of the RLG. Hold the load for 5 seconds in those cases where the test criterion is met, and then release it at the same crosshead speed.
5. Applied load and support surface deflection are recorded during the test.

## EVALUATION

Two sets of forty different types of WCSSs and components were tested using the static test method developed in this study. The results of the static tests showed similar failure modes observed during previously conducted sled impact testing. For example, during the static test, WC seats or backs which utilized drop hook type hardware failed to withstand the test criteria loads due to straightening of the hardware. Similarly, in sled tests conducted at University of Virginia Automobile Safety Laboratory (5), the seat inserts utilizing drop hook hardware were driven down through the WC frame as a result of the straightened drop hooks. Another example is that among statically tested WCSSs, most sling seats and sling backs withstood the test criteria loads, while most of other types of seating systems failed at loads less than 50% of the test criterion loads. Sled tests conducted by Bertocci also showed that the sling upholsteries were intact after 20g frontal impact sled tests (6).

## DISCUSSION

Two main limitations of this study are as follows: (1) Testing conducted in this study relies upon static loading conditions that are significantly different from the dynamic loading conditions found in sled testing; (2) The use a rigid test frame, surrogate attachment hardware, and a surrogate support surface in the study may not duplicate the yielding structure of commercial WC frames and seating systems. However, using rigid components is also one of the benefits of this study since it isolates the performance of each of the products.

The static test developed in this study can provide a preliminary screening of commonly used WCSS crashworthiness independent of specific WC frames. Moreover, this test method can aid manufacturers in the design of crash-safe seating components and systems.

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# Response of Tissue to Static and Dynamic Loading

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## ABSTRACT

Postocclusive hyperaemic response of cutaneous microcirculation is evaluated using the Laser Doppler Perfusion Imager at a site over the greater trochanter. Three types of loading: (static) pressure only, combination of pressure and shear, and (dynamic) combination of pressure and cyclic shear were applied to 4 healthy subjects and 6 active wheelchair users for a duration of 3 minutes each. Pressure loading of 172 mmHg was applied, with and without the application shear stresses. For dynamic loading, cyclic shear is applied at a rate of 1 Hz. Experimental results indicate that there exists significant difference in post occlusive hyperaemic response between normal and disabled subjects. Also, the peak hyperaemia after static loading with pressure and shear application in normal subjects is found to be significantly larger than the other loading situations, and half-life hyperaemia is found to be largest after dynamic loading. For disabled subjects, the hyperaemic responses under all three loading conditions are found to be similar.

## BACKGROUND

Decubitus ulcers (pressure sores) are serious complications of tissue damage developed in patients with diminished pain sensation and/or diminished mobility. Although the etiology of pressure sores is still not conclusive, it has been generally accepted that pressure and shear are the two major causative factors. Early study by Bennett et. al. [1] has demonstrated that combination of pressure and shear stresses was particularly effective in causing blood flow occlusion. This situation can be found at the interface with almost every body-supporting surface, such as cushions and mattresses. To prevent the on-set of pressure sores, early identification of tissue distress is of great importance. Reactive hyperaemia is a physiological phenomenon whereby tissue recovery after hypoxia is accelerated through a transient increase in blood flow. The response of skin blood flow to locally applied pressure has been studied in the past [2,3], which suggested that postocclusive reactive hyperaemic response can be used as an indicator for tissue viability, as well as a possible predictor for the risk of pressure sores.

## METHOD

Four young healthy male subjects and six active wheelchair users participated in this study. A cylindrical indentor of 51mm diameter was used to apply a mechanical loading of 24.5N (~172 mmHg) to a site over the greater trochanter for a duration of 180 seconds. In order to ensure constant load application, visual feedback was provided on the load applied. Blood perfusion was measured with the laser Doppler perfusion imager (Moor Instruments Ltd., UK) using the near infrared 780nm 1.5mW laser. Three loading conditions were prescribed for each subject, including static loading with vertically applied loading (pressure) and the combination of pressure and shear loading; and dynamic loading with the combination of pressure and cyclic shear. Prior to the indentation, one scan was performed to measure the resting perfusion level of the skin surface. Subsequent to the indentation a number image scans, each taking approximately 30 seconds, were performed to monitor the postocclusive reactive hyperaemic response of the tissue. Three loading trials were performed on each subject with sufficient resting period in between to allow skin circulation to return to its resting level. The application of shear loading was manually applied towards the distal end of the foot, with a force magnitude just less than the level that would cause slipping between the indentor and the skin surface. During cyclic shear loading, the indentor was guided to travel in the distal-proximal direction at an average rate of 1 Hz. This movement was carefully controlled to prevent causing any slippage at the skin-indentor interface. The magnitude of the induced shear stress was not measured.

## RESULT

There was no significant difference in perfusion found between the normal and the disabled groups before loading was applied. ($p=0.54$, 0.08 and 0.09 before the application of pressure only, combination of pressure and shear and combination of pressure and cycle shear loading). Following load release, it was observed that perfusion reached maximum during the first image scan for all subjects. The recorded peak flow after combined pressure and shear loading for normal subjects was found to be significantly higher than the disabled subjects ($P<0.05$). However, the half-life of hyperaemia for the normal and disabled subjects was not found to have statistically difference. In addition, for normal subjects, the peak hyperaemia after static loading with pressure and shear application was found to be significantly larger than the other loading situations ($P<0.05$), and half-life hyperaemia was found to be largest after dynamic loading (table 1). For disabled subjects, the hyperaemic responses under the three loading conditions were found to be similar. It was also observed that post-occlusive hyperaemia after static pressure loading was completed within the first 60 seconds in normal subjects, whereas for the disabled group, the hyperaemic responses was generally prolonged.

| | | Normalized Peak Perfusion | Half-life of Hyperaemia |
|---|---|---|---|
| **Normal Group** | Pressure Loading | 3.76(2.49) | 24.25(14.84) |
| | Pressure and Shear Loading | 6.80(4.1) | 48.55(32.9) |
| | Pressure and Cycle Shear Loading | 5.72(3.9) | 180.98(112.0) |
| | ***Significance*** | ***P<0.05*** | ***P<0.05*** |
| **Disabled Group** | Pressure Loading | 2.87(1.02) | 43.34(21.11) |
| | Pressure and Shear Loading | 2.8(1.27) | 197.1(165.76) |
| | Pressure and Cycle Shear Loading | 2.54(0.98) | 204.26(114.21) |
| | ***Significance*** | ***ns*** | ***ns*** |

Table 1: Within group evaluation on normalized peak perfusion and half-life hyperaemia over the greater trochanter following application of three loading conditions. Statistical significance was tested using Friedman test

## DISCUSSION

Hagisawa 1991 reported that resting skin blood flow is independent of age. However, Schubert [4] reported that chronic spinal injury patients have a higher resting skin blood flow than normal. In this study, it is observed that there is no significant difference in resting skin blood flow between the normal and the disabled group. For the post occlusive hyperaemic responses, no statistical difference is found between the two groups under vertical pressure loading condition. The parameters for evaluation included the peak flow and the time to half-life of hyperaemia. However, the duration of the hyperaemic responses for the normal group is found to be about 60 seconds, whereas for the disabled group, the duration is generally prolonged.

There is very little information in literature, which describe the hyperaemic responses to shear loading. In the present study, when combination of pressure and shear loading is applied, the peak perfusion for the normal group is significantly higher than the disabled group. Moreover, the half-life time of hyperaemia between the two groups does not show any difference. This suggests that the recoveries of tissue to anoxia in both groups are the same. The post-occlusive hyperaemic response of the normal group is observed to be different among the three loading conditions. The peak perfusion after pressure and shear loading is found to be highest, followed by the pressure and cyclic shearing condition and the pressure only loading situation. This demonstrates that shearing is an important parameter to tissue distress. Dynamic loading under pressure and cyclic shearing in normal subjects is found to significantly increased the half-life of hyperaemia. This suggests that the distress to tissue under such loading is most severe as the recovery of tissue from anoxia is prolonged. Although no significant difference in peak perfusion and half-life of hyperaemia can be found among the three loading conditions in the disabled group, it is observed that the hyperaemic responses of 3 subjects show a plateau in the first few scans after removal of pressure and cyclic shearing loading. The persisted peak flow could be attributed to the higher demand of oxygenated blood in trying to recover from a larger distress experienced by the local tissues.

## CONCLUSION

The result from this study suggests that combination of pressure and shear stress cause a higher distress to tissue than with pressure alone. It is also found that dynamic loading could cause high distress to tissue, which requires a prolonged period to recover.

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# MEASURING CHANGE IN INTERFACE PRESSURE: EFFECT OF REPOSITIONING AND TIME

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## ABSTRACT

Measurement of interface pressure is important in assessing tissue viability, as prolonged pressure can lead to pressure sore development. Allowing adequate settling time prior to measurement, and achieving consistent subject repositioning throughout measurement, are both essential. This pilot study investigated interface pressure changes on repositioning and over time. Findings suggest that neither Average or Maximum Pressures can be used to assess repositioning. Both these measures were shown to increase over both a one-minute and 20-minute period. During the latter, statistically significant changes occurred over the first 8 minutes, suggesting this may be the optimal waiting time prior to pressure recording.

## BACKGROUND

It has generally been accepted that high interface pressure maintained over prolonged periods of time can lead to the development of pressure sores in 'at risk' individuals (1). Measurement of interface pressure is therefore important in the assessment of tissue viability and in the prevention of pressure sores (2). Pressure measurements from systems, such as the Force Sensing Array used in the current study, can provide valuable data for decision-making to clinicians involved in pressure sore prevention.

Previous studies have shown that pressure measurements vary with different seating postures (3, 4, 5), and on repositioning (2). It is commonly accepted that pressure measurements change with sitting time. However, this cannot be attributed entirely to changes within the individual as the contribution of creep must also be considered in influencing this change. Creep is the intrinsic tendency for pressure to increase over time (6). This is due to both the pressure sensing mat and the seating surface. Further, consistency in repositioning must be considered if results are to be comparable, especially those evaluating the effectiveness of different support surfaces. A recent study by Al-Eisa *et al* (7) has demonstrated the potential to accurately reposition individuals over a number of seating trials.

## RESEARCH QUESTIONS

The two main purposes of this two-strand pilot study were as follows:
Strand 1: to examine changes in interface pressure after careful repositioning,
Strand 2: to investigate changes in interface pressure over a 20-minute sitting period in order to identify an optimal time for pressure measurement during clinical assessment.

## METHOD

*Subjects*

Strand 1: 44 student volunteers (43 female, 1 male) with age range 18-37 years.
Strand 2: 20 student and staff volunteers (6 male, 14 female), with age range 24-53 years.

*Procedure*

Interface pressures were measured using the Force Sensing Array (FSA) pressure mapping system. The system was calibrated according to the manufacturer's recommendations as given in the product manual (Vista Medical,Winnipeg). The same calibration was used throughout the study. Approximate changes in interface pressure due to the effect of creep were measured and accounted for during statistical analysis. The study took place over a 10-week period.

All pressure measurements were recorded with the participants seated on a non-adjustable armchair (12cm upholstered foam seat). Participants were asked to sit with their arms placed on the armrests and were positioned to allow $90^0$ flexion at hips, knees and ankles. Feet were supported if necessary. In Strand 1 of the study, interface pressure in the form of Average and Maximum Pressures (the mean of the sensor values and the highest individual sensor value respectively) were recorded using the Force Sensing Array system for a one-minute period. Participants were then asked to walk for a distance of 100 metres, and then sit as before for a second one-minute measurement period. This procedure was repeated for a third and final set of pressure measurements to be recorded.

In Strand 2 of the study, interface pressure measurements were recorded with the participants seated on the same armchair as above. They were instructed to adopt a comfortable position and maintain the same seating position for a twenty-minute period. During this time pressure measurements were recorded at two-minute intervals. Statistical analysis was performed using a paired samples t-test or a repeated measures ANOVA technique as appropriate.

## RESULTS

A significant increase in both Average and Maximum Pressure was found between the first and last second of each of the three one-minute recording periods.

No significant difference in Average Pressure was found between first seconds from each of the three one-minute recording periods. In contrast a significant increase in Average Pressure was identified between the final seconds of the recording period ($p<0.01$). A significant difference in Maximum Pressure was found at both the first and final seconds of the three one-minute recording periods ($p<0.05$).

Average Pressure was shown to generally increase over the 20-minute measurement period. A statistically significant increase between time intervals 0-2, 2-4, 4-6, 6-8 ($p<0.005$), and at 10-12 and 14-16 ($p<0.05$) minutes. However, the latter significance levels were thought to be related to a multiple testing effect, as there was no significant difference at the 8-10 minute measurement. A similar trend was found for Maximum Pressures.

## DISCUSSION

*Strand 1* Results showed a significant increase in both Average and Maximum Pressures over each of the one-minute recording periods after being positioned on the chair. Part of this increase may be attributed to creep, a factor intrinsic to the pressure measurement mat and to the foam in the seat. Pre-test measurements by the authors had shown that approximately 5% of the total pressure increase over a 20-minute period was due to creep with most increase occurring within the first minute of measurement.

Average Pressure did not differ significantly at the first second of each one-minute period, and from this it may be concluded that comparable Average Pressures can be achieved on repositioning during seating. Caution must be taken however in inferring that accurate repositioning had been achieved, as the same average pressure may be the result of many different seating positions. The significant difference found in Average Pressure at the final second of each of the three recording periods was expected, as a significant increase in average pressure over a one-minute seating period has been demonstrated above. In contrast to Average Pressure, values of Maximum Pressure on repositioning, at the first second of each one-minute recording period, differed significantly. As Maximum Pressure refers to the pressure in a single sensor it is generally considered to be an unstable measure (personal communication, June 2000, Vista Medical, Winnipeg). Such fluctuations in Maximum Pressure question its usefulness as a measure of reliability in repositioning. Perhaps a better method of measuring accuracy in repositioning is that recently adopted by Al-Eisa *et al* (7) who examined spatial measurement of the mean pressures within a 3x3 sensor block under the ischium. This method showed high reliability in repositioning subjects.

*Strand 2* Analysis of the changes in Average Pressure over a 20-minute sitting period, revealed a general increase, with a highly significant increase over the first eight minutes recording time ($p<0.005$). Although sporadic significant increases in Average Pressure occurred after eight minutes, specifically at time intervals 10-12 and 14-16 minutes ($p<0.05$), these significance values are thought likely to be influenced by the multiple testing effect.

Similar increases in Maximum Pressure were found over the 20-minute testing period. The increase in Maximum Pressure over the first two-minute sitting period was approaching statistical significance ($p = 0.058$). Strongly significant increases in Maximum Pressure were identified between 2-8 recording minutes ($p<0.01$), and these were similar to the changes observed in Average Pressure over this time period. Although statistically significant increases in Maximum Pressure during sitting were shown from 10-16 minutes ($p<0.05$), these significance values are again likely to have been artificially deflated by a multiple testing effect. No significant change in Maximum Pressure was observed between 16-20 minutes.

Overall, results suggest that in theory the optimum waiting time prior to recording pressure measurements is eight minutes for this seating surface, if the effects of multiple testing are considered. However, a replication study is planned to overcome the multiple testing effect thought to be evidenced in this pilot study and also to give due consideration to other seating surfaces.

Further studies using disabled subjects are necessary to establish the optimal settling time during clinical pressure mapping.

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# SITTING WITH REDUCED ISCHIAL LOAD

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## ABSTRACT

A new seat design characterised by unloading the ischia was investigated. The rear part of the seat could be tilted downward, so as to decrease the peak pressure under the buttocks. This study was aimed at investigating the biomechanical differences between conventional sitting and sitting without ischial support, using an instrumented chair enabling release of ischial support. Results showed that sitting without the ischial support induced considerable reduction in the peak seating pressure, forward shift of the center of pressure and changes in the pressure distribution, transfer of the lifting support to the backrest, and change in pelvis rotation.

## INTRODUCTION

Musculoskeletal discomfort in sitting work is reported at a prevalence of 25-76% among visual display unit (VDU) operators (Aarås et al. (1)). The reason for a high prevalence for such problems seems to be multifactorial and complex. One important factor is assumed to be the static muscle load, which may be caused by work posture and task.

Causes of different kinds of pain in the back area and the waist have been analysed by Laubli et al. (2) and research on chairs and sitting posture has taken place as a preventive measure.

A new patented seat design, where the posterior portion of the seat is lowered with respect to the anterior part providing the thigh support, introduces a new sitting concept. The main objective of this study was to investigate the differences between usual (flat seat) sitting and sitting with a lowered rear part of the seat.

Expected objective differences include:

- Lower pressure concentration (The ischial tubercles will be relieved)
- Different distribution of reactive forces from the chair (More load on the thighs and back)
- A slight backward tilt of the pelvis


Figure 1. The 'Erg-O-Sitter' chair equipped with stain gauges. ch1, ch2 and ch3 strain gauges for the chair legs, ch4-ch7 for the fixed part of the seat and ch8 at the base of the backrest. The left figure shows the pressure-mapping device and active markers. The distances indicated by double arrows are individually adjustable.

## MATERIAL & METHODS

***Chair*** A new chair design, 'Erg-O-Sitter', was selected for this study. The seat of the chair consisted of two parts. The front part was fixed and the back part of the seat could be tilted (Figure 1) (downward tilt 0°-30°). Lumbar support depth, height and shape were adjusted for different individuals. The chair was adjusted for different subjects to obtain a posture to fit the shape of the spine. Seat height and depth were also adjusted.

In order to find the load distribution in a sitting position, the chair was equipped with force transducers. Six strain gauges were used between three legs of the chair and the floor to measure forces carried by the chair legs and to calculate the position of the center of pressure in the sagittal plane. Eight strain gauges were used under the fixed part of the seat for measuring position of the center of pressure. Two stain gauges were used at the lower end of the backrest to measure the moment on the backrest. To avoid temperature drift, the strain gauges were used in pairs for each place of measurements and connected to a signal conditioning board in half-bridge configurations. An extensive set of measurements with different loads and load distributions were made to obtain calibration data.

A pressure-mapping device (Xsensor Pressure Mapping System) with 2 mapping pads was used to measure interface pressure on the seat and backrest.

Chair position, tilting angle of the back part of the seat pan, and the posture of the subject were measured by a motion capturing system (Optotrak, Northern Digital Inc.) with 12 active IRED markers stuck on the seat and backrest of the chair and on the thigh, pelvis, and back of the subject.

*Subjects* The experiment was performed on three subjects. The chair was adjusted for each subject (seat height, lumbar support depth, height and shape of the backseat). First, subjects were sitting upright in a comfortable position on the seat without using the backrest. Forces on the legs and the fixed part of seat, the pressure on the seat and backrest and posture of the chair and subject were recorded with and without tilting the back part of the seat.

Similarly measurements were made when the backrest and backrest and neck support were employed with and without the back part of the seat tilted downward. Before testing, the subjects were trained to perform correctly, i.e. not changing their positions during the experiment.

Load distribution parameters measured were:

xl, the center of the pressure normal to the floor acting on the legs of the chair. xs. the center of pressure on the fixed

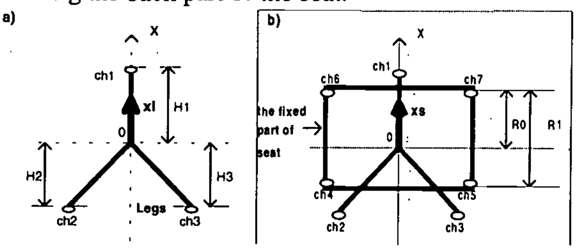


Figure 2. The geometry of the chair base and the positions of the strain gauges. a) The lengths H1, H2 and H3 necessary for the calculation of the centre of pressure of the forces normal to the floor acting on the legs of the chair. b) The lengths R0 and R1 describing the geometry of the strain gauge positions on the fixed part of seat relative to the chair

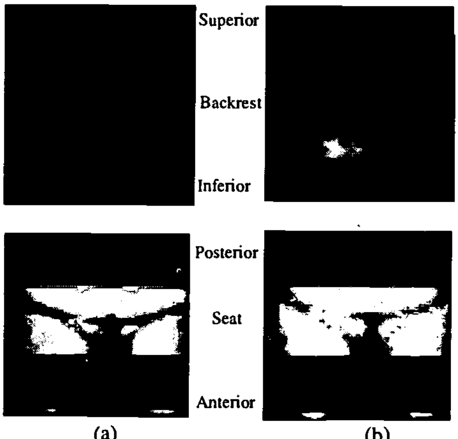


Figure 3. Pressure mapping on seating pan (lower row) & back support (upper row) before (a) and after (b) the back part of the seating pan was tilted down.

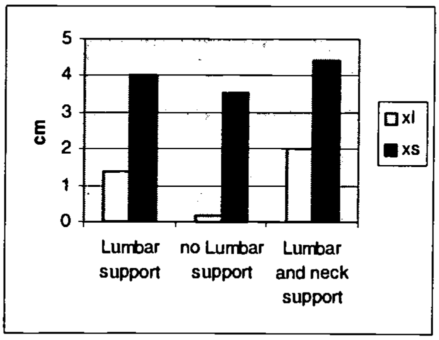


Figure 4. Changes of xl and xs when the back part of the seat is lowered. Diagram shows the averages of xl and xs form three subjects under investigated conditions (with and without lumbar support and with lumbar and neck support).

part of the seat chairs. The total load L carried by the chair, the total load K carried by the seat and the vertical load Fv on the backrest (Figure 2).

## RESULTS

*Pelvis tilting angle* Angle between pelvis and femur was calculated from subject's posture data measured by the Optotrak only for one subject who was slim with easily found bony landmarks on the pelvis and femur. It was found that pelvis rotated backward about 11° when the back part of the seat was tilted down about 19°.

*Pressure distribution on seat and backrest* Figure 3 shows the pressure mapping result before and after the back part of the seat was tilted down. A brighter color represented higher pressure. For all the subjects, similar results were obtained. As the back part of the seat was tilted down, pressure distribution on both seat and backrest changed significantly. On the seat pan, pressure distributed in a larger area with lower peak value and pressure shift to the thigh. Peak contact pressure between the ischia and the seat (red (brighter) area in the left column) was lowered significantly (yellow color in the same place as previously red), while the pressure of the backrest increased.

*Load distribution* When the backrest was utilised, all subjects got a significant raise in the vertical load taken up by the backrest. The extra vertical load on the backrest varied between 5% and 10% of body weight (This force tends to stretch the lumbar spine.).

The center of pressure on the seat (xs) and on the floor (xl) were moved forward significantly when the ischia support was removed and the backrest and neck support utilised (Figure 4). Lowering of the ischial support results in the following biomechanical changes:

- The ischial tubercles carry no external load. In upright position the thighs take up more load over a larger surface area. When the backrest is used, vertical load is to some extent taken up by the backrest. This part is larger without ischial support.
- The back is moderately stretched when the backrest is used and no ischial support employed, as compared to normal sitting.

## DISCUSSION

According to the literature using a backrest with a protruded part to support the lumbar part of the back would result in a reduction of the load on the back (Andersson et al. (3,4)). The present study supports such an observation. Furthermore, a much grater load reduction was shown in this study, when the ischial tubercles are relieved.

A number of beneficial effects of lowered ischial load seem likely. Anatomically, lowered ischia in sitting is likely to promote a slight backward rotation of the iliac, thereby also diminishing the lordosis. Secondary to this rotation would be a lowered peak seat pressure, with more weight carried by the thighs and the backrest.

In summary, the study showed considerable changes occurred with this new sitting design, including transfer of the vertical load to the backrest, lower pressure on the seat and forward translation of the center of pressure on seat. These changes are likely to be beneficial to the subjects, especially with prolonged exposure to sitting.

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# THE EFFECTS OF WHEELCHAIR SEATING SYSTEM ENERGY ABSORPTION ON OCCUPANT SUBMARINING RISK IN A FRONTAL IMPACT USING COMPUTER SIMULATION

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## ABSTRACT

The safety features of seat assemblies are key to motor vehicle occupant crash protection. To protect people with disabilities (PWD), wheelchair manufactures must begin to focus on the design of transport-safe products. The aim of the study was to investigate the effects of seat energy absorption properties on occupant risk of submarining during a frontal motor vehicle 20g/30mph impact. A validated computer crash simulation model was used to systematically examine the effects of energy absorption properties. The results indicate that wheelchair seat energy absorption characteristics affect occupant crash kinematics and submarining risk. A seat with relatively high-energy absorption was found to increase risk of submarining.

## INTRODUCTION

The motor vehicle industry spends substantial funds and a vast amount of time on research to define the most optimal seat design for drivers and passengers (5). Since people with disabilities (PWD) often travel seated in their wheelchairs, they are unable to realize the benefits of motor vehicle seat safety features. The interaction of the seat and occupant is an important aspect to safety and comfort (2). Seat design represented through seat stiffness and energy absorption properties can affect risk of submarining (lap belt over iliac crest onto abdomen) and injury in a crash (1,4). Previous research has shown that submarining risk in wheelchair users can be influenced by seat stiffness during a frontal motor vehicle crash (2,8). Bertocci and Szobota examined the effects of seat stiffness of a power-based wheelchair during a frontal crash using a computer crash simulation model. Vertical hip excursion (H-pt) was measured across a range of seat stiffness. They found that the softer seats increased occupant-submarining risk. The ANSI/RESNA WC-19 seat failure and submarining criterion evaluates the pre- and post-test change of the H-pt during a 20g/30mph frontal impact. This standard states that the vertical pre- to post-test H-pt excursion may not vary more than 20%. Viano and Arepally's submarining criterion limits H-pt vertical arc to no more than 1.97 inches.

## RESEARCH QUESTION

Do wheelchair seat energy absorption properties lower torso kinematics (H-pt excursion) and place PWD at risk of submarining during a frontal motor vehicle impact?

## METHODS

A parametric sensitivity analysis was conducted to examine the effects of wheelchair seat energy absorption on lower torso (hip) excursion in a frontal crash. A validated Dynaman computer crash simulation model utilized a power wheelchair seated 50$^{th}$ percentile Hybrid III anthropomorphic test device secured with 4-point strap-type tiedowns and a 3-point occupant restraint system (3). The restraint system consisted of a shoulder belt fastened to the vehicle and a lap belt attached directly to the wheelchair. The wheelchair and occupant system was subjected to an SAE J2249-compliant 20g/30mph frontal sled impact pulse.

The seating system used in the model was a foam cushion placed on a rigid phenolic seat pan with a 667-lb/in-midrange stiffness. The horizontal and vertical hip excursion was examined across a range of seat energy absorption properties. The two variables associated with energy absorption are the G-factor, representing the ratio of permanent deformation to maximum deformation, and the R-factor, representing the ratio of energy returned during unloading to total energy associated with maximum deformation (Figure 1). Simulations were conducted while varying the G and R factors according to the matrix in Table 1. The seating stiffness was held constant for all simulations.

Table 1. Simulation matrix of wheelchair seat G and R variable combinations used in the parametric sensitivity analysis.

| *Conditions* | *R = 0.00* | *R = 0.25* | *R = 0.50* | *R = 0.75* | *R = 1.00* |
|---|---|---|---|---|---|
| ***G = 0.00*** | X | X | X | X | X |
| ***G = 0.25*** | X | X | X | X | X |
| ***G = 0.50*** | X | X | X | X | X |
| ***G = 0.75*** | X | X | X | X | X |
| ***G = 0.99*** | X | X | X | X | X |

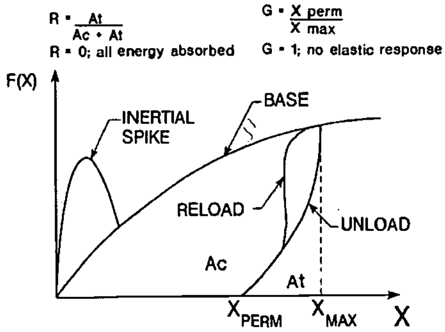


Figure 1. The R and G factor equations and graphical depiction of energy absorption.

## RESULTS

The parametric sensitivity analysis examining vertical H-pt excursion revealed that seat energy absorption scenarios with G-factors of 0.75 and 0.99 combined with R-factors from 0.00 to 0.75, may increase occupant submarining as evidence by comparison with the Viano and Arepally limit of 1.97 inches (Table 2 and 3). When comparing results of pre- to post-test H-pt excursion to the WC-19 criteria, energy absorption was found not to be a factor. Horizontal hip excursion showed little or no difference over each seat scenario. Figure 2 displays the horizontal and vertical H-pt trajectories for select (G=0,R=0; G=.50,R=0; and G=.99,R=0) seat scenarios.

Table 2. H-pt kinematics for seat energy absorption scenarios (G=0.00 to 0.99 and R=0.00 to 0.50) compared the Viano limit and ANSI/RESNA WC-19 standard. Shading indicates exceeded criterion.

| Condition | R-factor = 0.00 | | | R-factor = 0.25 | | | R-factor = 0.50 | | |
|---|---|---|---|---|---|---|---|---|---|
| G-factor | % Diff pre to peak H-PTvert | Peak H-pt vert/Viano limit | WC19 % Diff pre to post H-PTvert | % Diff pre to peak H-PTvert | Peak H-pt vert/Viano limit | WC19 % Diff pre to post H-PTvert | % Diff pre to peak H-PTvert | Peak H-pt vert/Viano limit | WC19 % Diff pre to post H-PTvert |
| 0.00 | 5.7% | 0.65 | -9.15% | 5.7% | 0.65 | -9.15% | 5.7% | 0.65 | -9.15% |
| 0.25 | 5.8% | 0.66 | -6.46% | 5.8% | 0.66 | -6.46% | 5.8% | 0.66 | -6.46% |
| 0.50 | 6.4% | 0.74 | -4.94% | 6.4% | 0.74 | -4.94% | 6.9% | 0.79 | -3.95% |
| 0.75 | 11.1% | 1.27 | -1.50% | 10.9% | 1.24 | -0.36% | 10.8% | 1.23 | 0.06% |
| 0.99 | 14.3% | 1.63 | 2.89% | 14.3% | 1.63 | 4.12% | 14.3% | 1.63 | 4.12% |

Note: (negative % indicates final H-pt position above initial position)

Table 3. H-pt kinematics for various seat energy absorption scenarios (G=0.00 to 0.99 and R=0.75 to 1.00) compared to Viano limit and ANSI/RESNA WC-19 standard limits. Shading indicates exceeded criterion.

| Condition | R-factor = 0.75 | | | R-factor = 1.00 | | |
|---|---|---|---|---|---|---|
| G-factor | % Diff pre to peak H-Ptvert | Peak H-pt vert/Viano limit | WC19 % Diff pre to post-test H-Ptvert | % Diff pre to peak H-Ptvert | Peak H-pt vert/Viano limit | WC19 % Diff pre to post H-Ptvert |
| 0.00 | 5.7% | 0.66 | -8.97% | 5.7% | 0.65 | -8.58% |
| 0.25 | 5.6% | 0.64 | -8.13% | 5.7% | 0.65 | -8.58% |
| 0.50 | 5.7% | 0.65 | -5.79% | 5.7% | 0.65 | -8.58% |
| 0.75 | 10.8% | 1.23 | 0.06% | 5.7% | 0.65 | -8.58% |
| 0.99 | 14.3% | 1.63 | 4.12% | 5.7% | 0.65 | -8.58% |

Note: (negative % indicates final H-pt position above initial position)

## DISCUSSION

Computer simulations indicate that wheelchair seating energy absorption characteristics can affect occupant kinematics associated with submarining risk. Although the WC-19 submarining criterion (20% difference in pre- to post-test vertical hip excursion) was not exceeded for any simulation, the Viano and Arepally limit was exceeded in several simulation scenarios. These findings suggest that wheelchair seats with relatively high levels of energy absorption can lead to lower torso excursion patterns, which are associated with increased risk of submarining. Question is also raised as to the ability of the WC-19 criterion to effectively capture and quantify submarining risk. This study provides evidence of the need for wheelchair seating manufactures to begin carefully addressing seating design characteristics to improve wheelchair user protection in a crash.

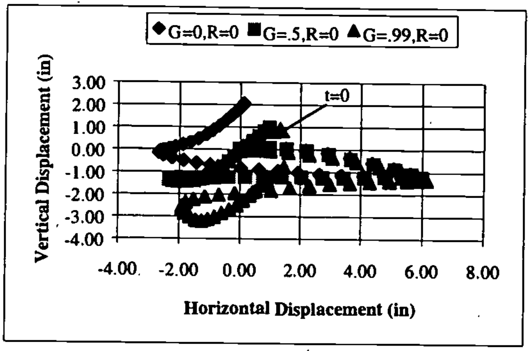


Figure 2. Trajectory of H-pt vertical and horizontal excursion for three different seat conditions.

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## ACKNOWLEDGEMENTS


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# INJURY RISK ANALYSIS OF A WHEELCHAIR USER IN A FRONTAL IMPACT MOTOR VEHICLE CRASH

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## ABSTRACT

Transport-safe wheelchairs must not only provide mobility for everyday use, but also sturdy and safe enough to protect the occupant in a vehicle crash. This study examined the injury risk associated with using a manual wheelchair as a vehicle seat in a 20g/30 mph frontal impact. The evaluation consisted of comparing injury criteria and ANSI/RESNA WC-19 requirements with sled test measurements. The influence of a rigid vs. sling seat and back was investigated. Results showed that seating type can influence injury risk and that wheelchair users may be at increased risk of neck injury when using rigid seats.

## BACKGROUND

The introduction of the Americans with Disabilities Act in 1990 required all modes of public transportation to accommodate wheelchair occupants. This presents a challenge to wheelchair designers. This challenge led to ANSI/RESNA WC-19, which is a standard that suggests safety guidelines for transport-safe wheelchairs (1). WC-19 includes manufacturing specifications and methods for testing wheelchairs used as seats in motor vehicles.

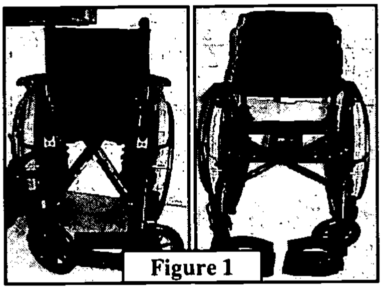
Figure 1

Sled tests were used to simulate a frontal impact at 48 km/h (30 mph). The vehicle occupant was an instrumented 50% male Hybrid III anthropomorphic test dummy (ATD). Two types of seating systems, sling-type and rigid-type (Figure 1), were tested on a manual folding wheelchair frame. The tests were conducted under the WC-19 standards for sled testing. Data sampled included belt loading, tri-axial neck forces, and excursions and accelerations of the ATD and wheelchair. The ATD was also equipped with a frangible abdomen to assess lap belt submarining risk. Collected biomechanical data was compared to known injury criteria and the WC-19 excursion limitations to determine occupant injury risk.

## RESEARCH QUESTION

What is the injury risk associated with an occupant using a manual wheelchair as a vehicle seat in a 20g/48km/h frontal impact?

## METHOD

Frontal impact sled tests were performed at the University of Michigan Transportation Research Institute (UMTRI). An instrumented 50% male Hybrid III ATD (168 lbs.) was seated in a wheelchair fitted with one of two seating configurations (Figure 2). The ATD was restrained using a basic three-point belt harness (shoulder and lap belts) anchored to the sled according to the specifications in WC-19. The wheelchair was secured using four strap-type tiedowns also anchored to the sled.

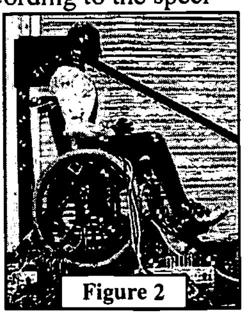
Figure 2

The wheelchair was purchased from the manufacturer with the transport option. Accordingly, the wheelchair was equipped with front and rear tiedown securement points. The frame is constructed of aluminum tubing and weighs approximately 20 kg (45 lbs.) including wheels. Two seating configurations (rigid and sling) using identical wheelchair frames were evaluated. The rigid-seat configurations (tests R1 and R2) consisted of a padded, molded plastic back and seat attached to the wheelchair frame with


Figure 3

drop hooks. The sling-seat configuration (tests S1, S2, S3, and S4) consisted of a nylon fabric seat and back. The sling seat configurations had a high-resiliency cushion attached to the seat using Velcro strips.

Prior to each test, the ATD was outfitted with a frangible abdomen (Figure 3). The frangible abdomen was developed as a tool to help assess lap belt submarining risk. It is a replaceable foam insert, which documents total deformation of the occupant's abdomen from lap belt loading during a crash. Extensive testing has proven the frangible abdomen's bio-fidelity and value as an indicator of injury (2).

The UMTRI sled operates on the rebound principle achieving the desired change in velocity (48kph/30mph) by reversing its direction of motion during impact. The secured wheelchair and occupant were subjected to an average 20 g sled deceleration. The impact event was recorded using a high-speed (1000 frames/sec) 16 mm motion picture camera positioned for a side view. Tri-axial accelerometers were used to measure accelerations of the sled, wheelchair, ATD head, chest, and pelvis during the test. Additionally, load cells recorded the force-time histories of the rear tiedowns, the lap belt, the neck, and the shoulder belt. Reflective markers placed at key locations on the wheelchair and ATD were used to obtain excursion data. Data generated during the test was multiplexed and recorded on a Honeywell Model 9600 magnetic tape recorder and digitized using a 486 processor. All signals were filtered following the requirements of SAE J211-2, instrumentation for impact testing. The collected, filtered data was compared to various injury criteria (3) and WC-19 excursion limits. The injury criteria applied to these tests focus on the neck forces, neck moments, head and chest accelerations, frangible abdomen deformation, and wheelchair, head and knee excursion limits.

**RESULTS**

*Wheelchair Damage*

Examination of the wheelchair frames after the tests revealed major fractures in tests S1 and S3. Test S1 wheelchair fractured at the weld point connecting the right crossbar support and the sling-seat bar. Test S3 fractured the welds on both left and right crossbars. Test S2 wheelchair has slight cracking in the weld connecting the right crossbar support. Tests S4, R1, and R2 wheelchairs appeared to remain structurally sound. The back supports of all the wheelchairs had some degree of rotation from their pre-test positions. The left chair back upright rotated rearward in all cases except test S2.

*ATD Injury Criteria and Excursion Limit Evaluation*

Across all tests, the ATD showed no signs of potential injury due to excessive neck moments or compressive neck forces. However, both test R1 and R2 wheelchairs with rigid-type seats exceeded the neck tension and shear injury criteria. Of the wheelchairs with sling-type seats, test S2 exceeded the neck tension criterion and test S3 exceeded the neck shear criterion. All other sling seat tests were marginally below the neck injury criteria except test S1, which was well below the neck force injury criteria.

In all cases, the frangible abdomens showed only slight deformation on the outer crests. This indicates submarining risk was low in all tests. The three main crests showed deformations leading to less than a 5% chance of AIS>3 injury and less than 1% of AIS>4 injury.

The head injury criterion (HIC) predicts the probability of life threatening brain injuries. The HIC is an algorithm that examines the time weighted acceleration history of the head. Questions exist concerning the time interval used to calculate HIC values. For this reason, UMTRI computed two separate HIC values; the $HIC_{unlimited}$ and $HIC_{32}$, which correspond to an unlimited time interval and a 32 ms time interval respectively. Tests S2, S4, and R2 had HIC unlimited values which exceeded the FMVSS limit of 1000 (Table 1). Table 1 also shows the tests that exceeded the neck injury criteria and the WC-19 excursion limits.

| | max | Test R1 | Test R2 | Test S1 | Test S2 | Test S3 | Test S4 |
|---|---|---|---|---|---|---|---|
| Neck Tension | (3) | **Yes 1100 N for 45 ms** | **Yes 1500 N for 42 ms** | No | **Yes 1100 N for 45 ms** | 3 ms notch at 1100 N | 2 ms notch at 1100 N |
| Fore/Aft Shear | (3) | **Yes 1500 N for 25 ms** | **Yes 1600 N for 20 ms** | No | 3 ms short at 1600 N | **Yes 1600 N for 20 ms** | 5 ms short at 1500 N |
| Head Excursion (mm) | 650 | 515 | 641 | 476 | 565 | 494 | 591 |
| Knee Excursion (mm) | 375 | 209 | 287 | 236 | 265 | 265 | 292 |
| Whlchr Excursion (mm) | 200 | 61 | 142 | N/A | 31 | 22 | 31 |
| $HIC_{unlimited}$ | 1000 | 890 | **1269** | 644 | **1089** | 965 | **1204** |
| $HIC_{36}$ | 1000 | 534 | 934 | 340 | 620 | 596 | 866 |

Note: Bold values indicate exceeded injury criteria

**Table 1**

## DISCUSSION

Comparison with injury criteria shows that the neck forces occurring in frontal impact may pose the greatest risk of injury. Both wheelchair tests with rigid seats exceeded the neck force injury criteria in shear and tension. Two of the four wheelchairs with sling seats exceeded the neck injury criteria; one in tension and one in shear. The averaged HIC values for the rigid seat tests were 100 points higher than the sling seat tests.

Two of the six tests fail to meet the structural integrity requirement set by WC-19. Section 5.3.g of WC-19 requires no structural failure, other than deformation or yielding, of primary occupant load-carrying parts. Since the welds connecting the support crossbars to the parallel sling seat bars fractured in tests S1 and S3, these wheelchairs fail to comply with WC-19. WC-19 also poses excursion limits on the wheelchair and occupant during the test. The excursions of all tests were within the allowable ranges.

Tests show variability in the safety of a wheelchair depending on the seating system. Both rigid-seat configured wheelchairs passed WC-19, but the injury criteria assessment showed that the rigid seat wheelchairs may pose a greater risk of neck injury than sling seats. This study illustrates that different seating configurations do affect injury risk.

Additionally, the use of excursion limits alone is not sufficient to predict injury risk. Accurate prediction of injury must also consider occupant forces and accelerations. This study suggests that WC-19 should require manufacturers to meet more stringent safety criteria to ensure occupant safety.

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## ACKNOWLEDGEMENTS

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# DESIGN CRITERIA FOR MANUAL WHEELCHAIRS USED AS MOTOR VEHICLE SEATS USING COMPUTER SIMULATION

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## ABSTRACT

Wheelchair users are often unable to transfer to a vehicle seat and must remain in their wheelchairs in motor vehicles. Since manufacturers traditionally design wheelchairs for mobility, these passengers may be traveling in seats that are inherently less safe than normal vehicle seats. This study defines the dynamic loading on manual wheelchairs in a 20g/30 mph frontal crash with sled test data and a validated computer model. Factors examined include seat and wheel loading, tiedown securement point loading, and restraint harness forces.

## BACKGROUND

With the adoption of the Americans with Disabilities Act (ADA), the demand for travel-safe wheelchairs is increasing. The purpose of this study is to demonstrate the dynamic loading on a manual wheelchair in a 20g/30 mph frontal crash. This type of data has been demonstrated for the heavier, power-based wheelchair (1). Manufacturers may use this data as a guide to increase the safety of wheelchairs used as motor vehicle seats. Dynamic wheelchair loads were calculated using data collected from sled testing and from a computer model developed with the Dynaman ATB simulation software.

## METHOD

A frontal impact sled test was conducted at the UMTRI testing facility following the ANSI/RESNA WC-19 standard (2). A 46 lb manual wheelchair with a welded aluminum frame was secured to the sled using four tiedown straps attached to securement points on the frame. The wheelchair occupant was a Hybrid III 50% male ATD. The ATD was restrained using a three-point harness (shoulder and lap belt) anchored to the sled. The sled simulates a 30-mph/20 g frontal impact. Table 1 shows the physical specifications of the wheelchair, tiedowns and restraints used in the sled test. Data sampled included accelerations and excursions of the ATD and wheelchair, occupant restraint and tiedown loads, and the sled acceleration pulse.

**Table 1: Sled test setup conditions**

| | |
|---|---|
| **Wheelchair** | |
| Wheelchair Weight | 46 lbs. |
| Rear Hub to Wheelchair Center of Gravity | 4.75" in front<br>2.75" above |
| Seatback Height | 20" |
| Seat Depth | 19" |
| Seat Height | 18.75" |
| Seat Frame Width | 15" |
| Rear Hub Height | 12" |
| Caster Hub Height | 3.5" |
| Rear Tiedown Location | 13.5" above sled |
| | 1.5" above rear hub |
| | 5.5" behind rear hub |
| Front Tiedown Location | 9.5" above sled |
| | 3" below rear hub |
| | 17.5" fore of rear hub |
| **Tiedowns and Occupant Restraints** | |
| Tiedown Angle wrt Horizontal | 40° |
| Rear Tiedown Angle wrt Centerline | 0° |
| Front Tiedown Angle wrt Centerline | 20° |
| Upper Shoulder Belt Anchor | 46.5" above sled |
| | 11" behind ATD shoulder |
| | 12" left of centerline |
| Lap Belt Anchors | 20.5" behind rear hub |
| | 9.75" outboard of centerline |
| Lap Belt Sag. Plane Angle wrt Horizontal | 56° |
| Shoulder Belt Sag. Plane Angle wrt Horizontal | 33° |
| Shoulder Belt Frontal Plane Angle wrt Horizontal | 59° |

A computer model using Dynaman was constructed matching the actual test conditions. The ATD and wheels were modeled with deformable ellipsoid segments connected by joints. The sled and wheelchair surfaces were modeled as a series of planes. The tiedowns and restraint belts were modeled as elastic harnesses with movable segment contact points. All contact surfaces and material properties were governed by force-deflection, energy absorption, and elastic functions. These functions were adjusted so that the computer simulation results matched overall occupant kinematics and data collected from sled testing. Once the model was validated, it was used to investigate the loads imposed upon manual wheelchairs during frontal impact. The influences of seat stiffness and rear tiedown location were also assessed.

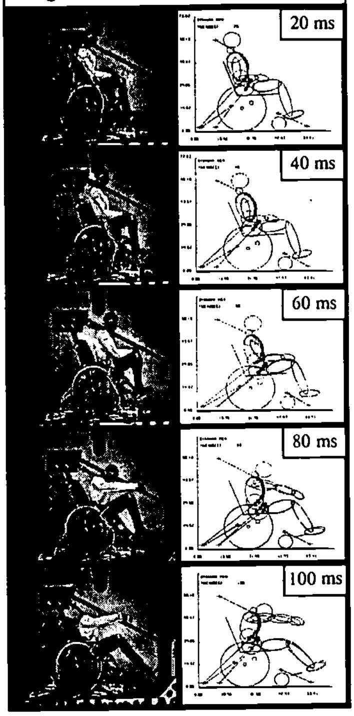
## RESULTS

*Sled Test vs. Simulation Results*

Figure 1 contrasts gross occupant and wheelchair kinematics of the sled test and the computer simulation at 20, 40, 60, 80, and 100-msec. Overall kinematics are comparable between the sled test and the simulation. The tie point between the shoulder belt and the lap belt is on the ATD's right hip. Figure 2 shows the tiedown and restraint loads from the sled test (TEST) and the computer model (SIM). The shoulder belt tension reached 2200 lbs for the sled test and the computer model. Rear tiedown tension peaked at near 1400 lbs for both the test and the simulation. The simulation lap belt data represents both left and right lap belt tension in the computer model. Sled test left side lap belt tension peaked at over 3500 lbs, while the right side lap belt tension peaked at 2300 lbs. Simulated lap belt tension peaked at 1500 lbs.

Figure 3 shows the accelerations of the pelvis, wheelchair, and chest in both the sled test and the computer model. The accelerations shown are the resultant accelerations of the tri-axial accelerometer measurements in the sled test ATD and the output from the computer simulation. Wheelchair acceleration was measured at the wheelchair center of gravity. Sled test and simulation acceleration peaks and profiles match quite well.

**Figure 1: Sled Test vs. Simulation**




*Design Criteria using Computer Simulation*

Figure 4 shows loading of the wheels and rear securement points based on three different rear securement point positions; 1.5" above the rear hub, 5.5" above the rear hub, and 2.5" below the rear hub. The rear wheel peak loads ranged from 2000 to 4000 lbs, while the front wheels peaked between 200 and 2000 lbs, depending upon securement point location. The front wheels lifted off the ground when the securement points were 5.5" above the rear

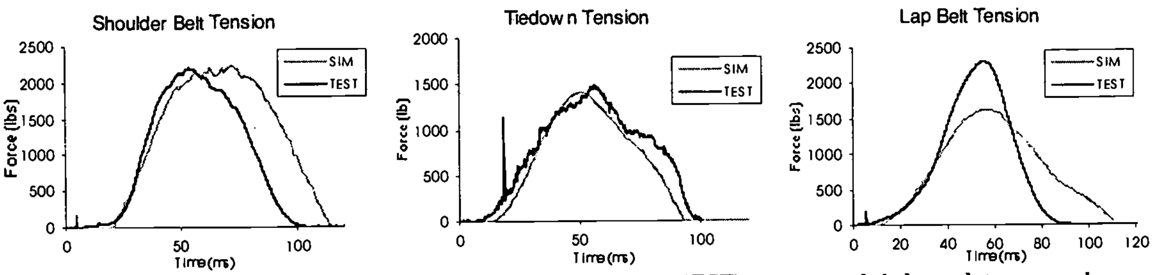



**Figure 2: Computer simulation output (SIM) and sled test data (TEST) harness and tiedown data comparison**

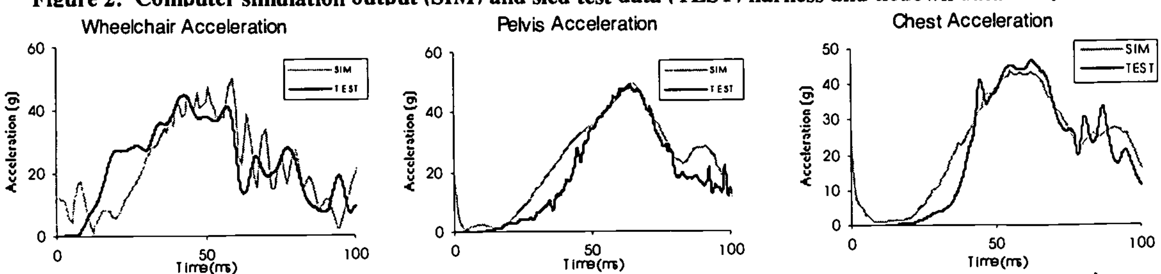



**Figure 3: Computer simulation output (SIM) and sled test data (TEST) resultant acceleration data comparison**

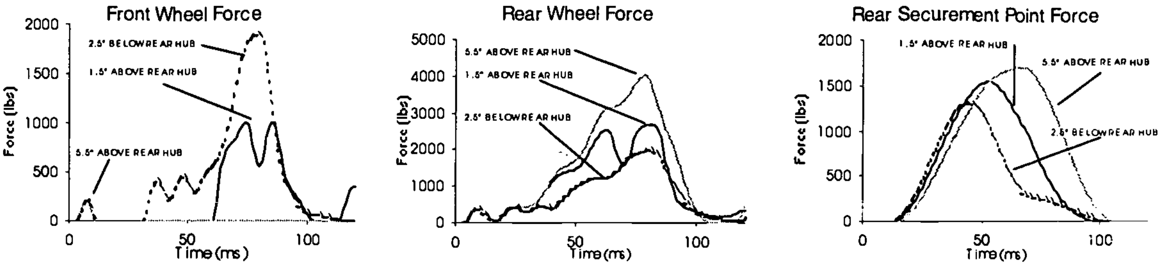



**Figure 4: Effect of rear securement point vertical position on simulated wheel and securement point forces**

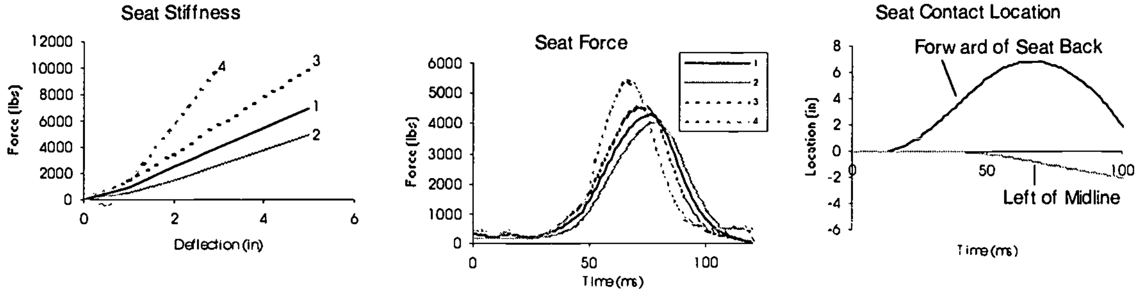



**Figure 5: Effect of variable seat stiffness on simulated seat force**

hub resulting in negligible front wheel loading. Tiedown tension varied from 1300 to 1700 lbs, depending upon securement point location.

The seat force calculated by the computer model is shown in Figure 5. With securement point location held constant, seat force was shown to depend on seat stiffness. Four seat force-deformation stiffness functions were used to produce the seat force time-history curves shown above. The model predicts a peak seat force location that moves forward 6 inches and left 2 inches during the simulation relative to the initial contact position. Seat loads varied from 4000 to 6000 lbs, with higher loads associated with stiffer seat surfaces.

## DISCUSSION

Overall ATD and wheelchair kinematics, belt tensions, and accelerations confirm that the computer model is a reasonably valid representation of the sled test. The computer model determines the effect of wheelchair variables such as seat stiffness and anchor position quickly and efficiently. Results show that vertical rear securement point position has relatively little effect on tiedown tension but greatly influences wheel loading and wheelchair stability. Securement point positions at or below the wheelchair CG tended to reduce overall wheel loads. Seat stiffness greatly influences seat loading. Of the seat stiffness scenarios evaluated, those with lower stiffnesses led to the lowest seat loads. This study demonstrates the usefulness of computer simulation techniques and provides manufacturers with guidance in the design of transport-safe manual wheelchairs.

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2. ANSI/RESNA. WC-19 Wheelchairs Used as Seats in Motor Vehicles, April 2000.

## ACKNOWLEDGEMENTS

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## COMPUTER SIMULATION VALIDATION OF A WHEELCHAIR MOUNTED OCCUPANT RESTRAINT SYSTEM UNDER FRONTAL IMPACT

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**ABSTRACT**

During motor vehicle impact, occupants using seat integrated occupant restraint systems experience an improved level of safety [1]. A fixed vehicle mounted (currently used) occupant restraint scenario and an upper torso and pelvic restraint was mounted to a wheelchair seat system and sled impact tested (20g/30mph frontal impact) using an instrumented Hybrid III 50th percentile male test dummy. Wheelchair, restraint and occupant loads, accelerations and excursions were recorded during the sled impact test. Sled test data demonstrated feasibility of a wheelchair integrated occupant restraint system (WIRS). Sled test data was then utilized to create and validate a computer simulation model of the WIRS. This validated computer model has the potential to assist in evaluating WIRS seat and restraint design characteristics, and their effect on occupant risk of injury in motor vehicle impacts.

**BACKGROUND**

An increased number of wheelchair users use their wheelchairs as motor vehicle seats during transport. Wheelchair securement systems are used to secure wheelchairs in a motor vehicle. Wheelchair occupant restraint systems (WORS) existing of upper torso and pelvic belts are used to secure occupants within their wheelchairs during transport in motor vehicles. Research shows that the use of WORS mounted fixed to the motor vehicle (FWORS) and installed according to SAE J2249 guidelines for a 50th percentile male user, very likely results in compromised belt-fit when used for various sized occupants and wheelchairs [2]. Computer crash simulations showed a reduced risk of occupant injury when integrating a WORS in the frame of a wheelchair [3]. An important step towards an integrated pelvic restraint has been made in ANSI/RESNA Vol.1 part 19, a voluntary standard that requires the integration of a pelvic belt as part of the wheelchair when used in transportation [4].

A recent study evaluated occupant risk of injury when using a WIRS versus a FWORS to restrain a Hybrid III ATD during a frontal sled impact test with a crash pulse of 20 g and 30 mph change in velocity [5]. When using the WIRS, higher rear wheelchair tie-down loads were seen, due to the additional weight of the occupant and WIRS. Lower shoulder belt loads were generated with the WIRS, resulting in decreased chest compression. Increased head excursions were found when using the WIRS, which was related to a lower stiffness of the upper torso anchor point, which was attached to the wheelchair seat back. The sled impact test indicated compliance of the WIRS with current occupant injury criteria and kinematic motion and excursion criteria according to GMIARV and SAE J2249 guidelines [6, 7]. Computer simulation needs to be conducted to further evaluate the effect of wheelchair seating system and occupant restraint characteristics of a WIRS and to study the effect of these characteristics on wheelchair kinematics and occupant risk of injury.

**RESEARCH OBJECTIVE**

The goal of this research is to develop a computer model using acquired sled impact test data to simulate the effect of a WIRS on wheelchair and occupant kinematics, restraint system loads and occupant injury risk when used in a motor vehicle during impact.

**METHOD**

Simulation Model: A commercially available version of an Articulated Total Body crash victim simulator, DYNAMAN (version 3.0), was used to develop a computer simulation of a WIRS and occupant subjected to a 20g/30mph frontal impact. The model was also used to evaluate occupant, wheelchair and restraint system dynamics under frontal crash conditions. The WIRS consists of a three-point harness fixed to a customized seat and back support surface, which is mounted to the base of the SAE J2249 surrogate wheelchair [7]. The seat back segment exists of a seat back plane and the upper torso restraint anchor point. A (non-fixed) pin joint connects the upper torso restraint anchor point to the seat back segment which is connected to the wheelchair. The pin joint characteristics enable the seat back to rotate relative to the wheelchair segment simulating seat back flexion. A validated model of a Hybrid III ATD is used to represent a 50th percentile male occupant. Improved neck pivot and head pivot characteristics of the Hybrid III dummy were implemented in the model according to a pendulum test done at the Systems Research Laboratories, Dayton, Ohio, March 1997. The WIRS crash pulse characteristics of the previously conducted sled impact test were used for the simulation model.

Validation Setup: Previously collected data from a WIRS sled impact test conducted at the University of Michigan Transportation Research Institute (UMTRI) were compared to WIRS simulation model data from DYNAMAN (DYN). Comparisons of acceleration-, load- and excursion-time histories of the wheelchair, restraint system and occupant were made between the WIRS simulation model and previously collected WIRS sled impact test data.

## RESULTS

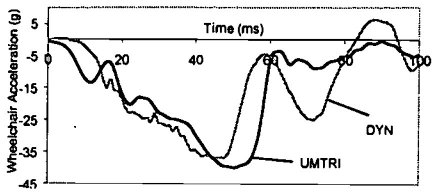


*Figure 1: Wheelchair acceleration of sled impact test data (UMTRI) versus simulation data (DYN)*

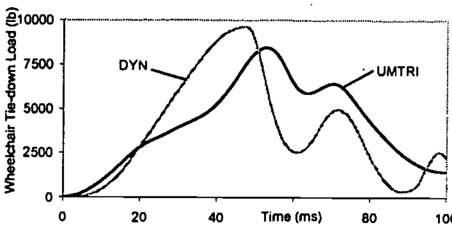


*Figure 2: Wheelchair tie-down load of UMTRI versus DYN data*

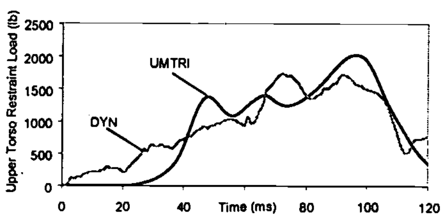


*Figure 3: Upper Torso Restraint Load*

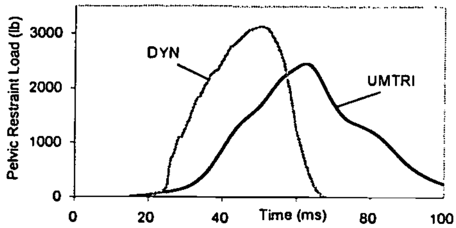


*Figure 4: Pelvic Restraint Load*

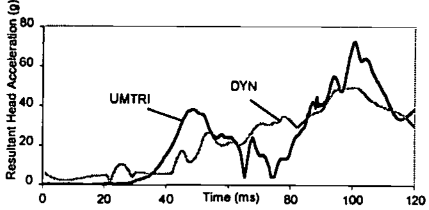


*Figure 5: Resultant Head Acceleration*

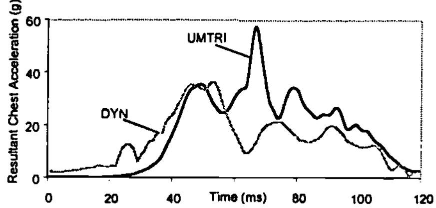


*Figure 6: Resultant Chest Acceleration*

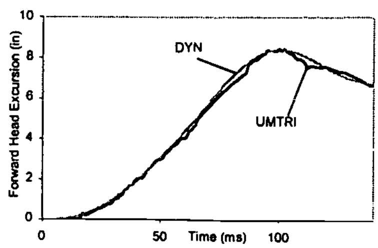


*Figure 7: Forward Head Excursion*

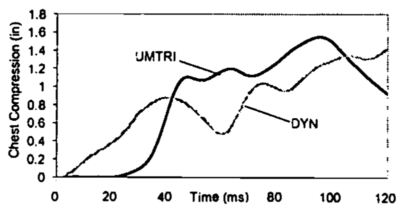


*Figure 8: Chest Compression*

WIRS COMPUTER SIMULATION

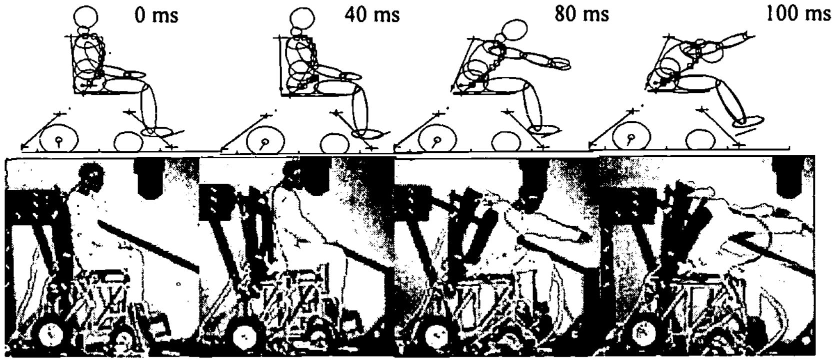


*Figure 9: Comparison of the WIRS DYNAMAN model versus WIRS UMTRI sled impact test*

Figures 1 through 8 show the comparison between the wheelchair, head and chest accelerations, tie-down and occupant restraint loads, head excursion and chest compression of the WIRS sled impact test and the simulation model data. Figure 9 compares overall gross motion of the ATD and wheelchair at 0, 40, 80 and 100 ms.

**DISCUSSION AND CONCLUSIONS**

The presented data of the WIRS simulation model follows similar trends to those of the UMTRI test data. Differences between the simulation model and the sled impact test data may be caused by the limited sled impact test data that was available to build and validate the WIRS simulation model. Furthermore, simplification of wheelchair and seating system, as well as the simulated occupant used in DYNAMAN might have caused differences. The WIRS computer model is useful to evaluate preliminary effects of wheelchair seat, back and restraint characteristics on occupant injury risk, wheelchair kinematics and tie-down / occupant restraint loads. Additional sled testing is needed to further validate the WIRS computer model.

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**ACKNOWLEDGEMENTS**

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# STATIC, IMPACT, AND FATIGUE TESTING OF FIVE DIFFERENT TYPES OF ELECTRIC POWERED WHEELCHAIRS

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## ABSTRACT

Electric powered wheelchairs must be able to withstand normal wear and tear during use. The American National Standards Institute and RESNA have developed standards that test for strength and durability. Comprehensive and current results for power wheelchairs are needed. Five types of powered wheelchairs were tested in accordance with these standards. Three Everest and Jennings wheelchairs failed when a static force was pushed against the footrests and when a static force was pulled up against the footrests. Three Quickies failed when a static force was pulled up against the armrests. One Everest and Jennings failed the Double Drum Test and two Permobils failed the Curb Drop Test. The results of these tests can serve as a purchasing selection guide.

## BACKGROUND

Powered wheelchairs require considerable dependability, since they are typically used all hours of the day, every day of the year. A broken powered wheelchair can leave the user stranded for long periods of time while the wheelchair is being repaired. ANSI/RESNA have developed 18 standards that test for performance, safety, and dimensions of wheelchairs. Manufacturers are not required to have their wheelchairs subjected to any of these tests. Davies discussed the durability of the Invacare Action Storm, Sunrise Medical Quickie P300, Everest & Jennings Lancer 2000, Permobil Chairman, and Pride Healthcare Jazzy, but durability was based on the opinions of repairmen (1). The National Rehabilitation Hospital tested power wheelchairs using ANSI/RESNA standards (2), but comprehensive and current data are still needed.

Five different types of power wheelchairs were selected for this study and tested in accordance to static, impact, and fatigue testing of the ANSI/RESNA standards (3), which is designed to evaluate whether wheelchairs can withstand the normal wear and tear during use (4). Static tests involved applying a static force and impact tests involved hitting specified parts of the wheelchair with a pendulum. The fatigue testing involved rolling the wheelchairs over two slated drums (Double Drum Test) and dropping the wheelchair 5cm from the ground (Curb Drop Test).

## RESEARCH QUESTION

Is there a difference in the static, impact, and fatigue strengths of five different types of power wheelchairs when tested in accordance to the ANSI/RESNA Standards (Section 8)?

## METHODS

Three wheelchairs of each type were purchased. This included the Invacare Action Storm, Sunrise Medical Quickie P200, Everest & Jennings Lancer 2000, Permobil Chairman, and Pride Healthcare Jazzy. These wheelchairs were purchased without the manufacturer's knowledge. The wheelchairs were tested for static strength, impact strength, and fatigue testing according to the ANSI/RESNA Standards (Section 8). A 100kg dummy was used when required. Failure of a test involved permanent damage, deformation, or an inability to operate the wheelchair. A wheelchair must have been able to complete 200,000 cycles for the Double Drum Test and 6,666 cycles for the Curb Drop Test without failure. Any damaged parts were replaced after the completion of each test.

**Table 1.** *Summary of Static Results*

| Wheelchair | Armrests Downward | | Footrests Downward | | Tipping Levers Down | | Handgrips | | Armrests Upward | | Footrests Upward | | Push Handles Upward | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Left* | *Right* | *Left* | *Right* | *Left* | *Right* | *Left* | *Right* | *Left* | *Right* | *Left* | *Right* | *Left* | *Right* |
| #1 Invacare | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
| #2 Invacare | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
| #3 Invacare | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
| #1 Quickie | P | P | P | P | N.A.[1] | | P | P | *F* | *F* | P | P | P | P |
| #2 Quickie | P | P | P | P | N.A.[1] | | P | P | *F* | *F* | P | P | P | P |
| #3 Quickie | P | P | P | P | N.A.[1] | | P | P | P | *F* | P | P | P | P |
| #1 E&J | P | P | *F* | *F* | P | P | P | P | P | P | *F* | *F* | P | P |
| #2 E&J | P | P | P | *F* | P | P | P | P | P | P | *F* | *F* | P | P |
| #3 E&J | P | P | *F* | P | P | P | P | P | P | P | N.A.[2] | | P | P |
| #1Permobil | P | P | P | P | N.A.[1] | | N.A.[1] | | N.A.[1] | | P | P | N.A.[1] | |
| #2Permobil | P | P | P | P | N.A.[1] | | N.A.[1] | | N.A.[1] | | P | P | N.A.[1] | |
| #3Permobil | P | P | P | P | N.A.[1] | | N.A.[1] | | N.A.[1] | | P | P | N.A.[1] | |
| #1 Pride | P | P | P | | N.A.[1] | | N.A.[1] | | N.A.[1] | | P | | N.A.[1] | |
| #2 Pride | P | P | P | | N.A.[1] | | N.A.[1] | | N.A.[1] | | P | | N.A.[1] | |
| #3 Pride | P | P | P | | N.A.[1] | | N.A.[1] | | N.A.[1] | | P | | N.A.[1] | |

[1] Wheelchair was not fitted with tipping levers, push handles, handgrips, or parts could not be tested because there was no locking mechanism.
[2] Test could not be performed because wheelchair failed previous test and replacement part was not available.

**Table 2.** *Summary of Impact and Fatigue Strength Results*

| Wheelchair | Backrest: Resistance to Impact | Casters Resistance to Impact | | Footrests: Lateral Impact | | Footrests: Longitudinal Impact | | Double Drum Test | Curb Drop Test |
|---|---|---|---|---|---|---|---|---|---|
| | | *Left* | *Right* | *Left* | *Right* | *Left* | *Right* | | |
| #1 Invacare | P | P | P | P | P | P | P | P | P |
| #2 Invacare | P | P | P | P | P | P | P | P | P |
| #3 Invacare | P | P | P | P | P | P | P | P | P |
| #1 Quickie | P | P | P | P | P | P | P | P | P |
| #2 Quickie | P | P | P | P | P | P | P | P | P |
| #3 Quickie | P | P | P | P | P | P | P | P | P |
| #1 E&J | P | P | P | P | *F* | *F* | *F* | *F* | N.A.[1] |
| #2 E&J | P | P | P | *F* | *F* | *F* | P | P | P |
| #3 E&J | P | P | P | N.A[1] | N.A.[1] | N.A.[1] | *F* | P | P |
| #1 Permobil | P | P | P | P | P | P | P | P | *F* |
| #2 Permobil | P | P | P | P | P | P | P | P | *F* |
| #3 Permobil | P | P | P | P | P | P | P | P | P |
| #1 Pride | P | P | P | P | | P | | P | P |
| #2 Pride | P | P | P | P | | P | | P | P |
| #3 Pride | P | P | P | P | | P | | P | P |

[1] Test could not be performed because wheelchair failed previous test and replacement part was not available.

## RESULTS

The results of the static tests are shown in Table 1. All three Quickies failed when the required 750N force was pulled up against the armrests (Armrests Upward Test) because the rear poles of the armrests lifted out of the their housings. All three Everest & Jennings wheelchairs failed when the required 1000N force pushed down on the footrests (Footrests Downward Test) and when the required 440N force pulled up on the footrests (Footrests Upward Test). In both tests the footrests deformed so that they could not be safely reattached to the wheelchair.

The results of the Impact and Fatigue Tests are shown in Table 2. All three Everest & Jennings failed when the pendulum struck the front and side of the footrests (Longitudinal and Lateral Impact Test). In both tests the footrests deformed so that they could not be safely reattached to the wheelchair. One Everest & Jennings wheelchair failed to operate after 23,712 cycles on the Double Drum Test. Two of the Permobils failed when dropped (Curb Drop Test) because of disconnected electrical connectors, which were detected at 811 cycles and 6666 cycles.

## DISCUSSION

The static tests are designed to simulate a person pushing down on the armrests, footrests, and tipping levers, holding the handgrips while bringing a wheelchair down steps, and lifting with the armrests, footrests, and push handles (5). Based on the results, the footrests of the Everest & Jennings might be more inclined to fail when hit against an object or when an attendant lifts the wheelchair by the footrests. The armrests of the Quickie might be more inclined to fail when an attendant lifts the wheelchair by the armrests. The impact tests are designed to simulate the user hitting against the backrest and having the casters and footrests hit against walls, etc. The footrests of the Everest & Jennings might be more inclined to fail when hit against objects from the side or front. The Double Drum Test is designed to simulate a wheelchair running over rough terrain. According to the fatigue testing results, the Everest & Jennings might be more apt to fail prematurely. The electrical connectors of the Permobil might be more likely to disconnect when repetitively driven down sidewalk curbs. Stronger and more durable powered wheelchairs are more cost-effective and reliable. These results can serve as a guide for wheelchair purchases.

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# ANALYSIS OF WHOLE-BODY VIBRATIONS ON MANUAL WHEELCHAIRS USING A HYBRID III TEST DUMMY

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## ABSTRACT

According to the literature, prolonged exposure to whole-body vibrations can have damaging effects on physiological systems, specifically the musculoskeletal system and the central nervous system. A total of five manual wheelchairs, two suspension wheelchairs, two solid frame wheelchairs, and one folding wheelchair, traversed two obstacles that represent the oscillatory and shock vibrations frequently encountered by wheelchair users. By measuring the vibrational dose value (VDV) of the oscillatory vibrations and the peak-to-peak values of the shock vibrations, the transmission of vibrations from the wheelchair to a Hybrid III dummy could be measured. All of the variables studied were found to be significantly different for our test wheelchairs, where the Quickie XTR suspension wheelchair and the Ti Sports rigid frame wheelchair were found to yield the lowest transmitted vibration levels in both tests. The results from this study could be used to enhance the development of suspension wheelchairs and reduce harmful secondary injuries to wheelchair users, leading to a better quality of life.

## INTRODUCTION

In the United States there are approximately 1.4 million people (1) who rely on wheelchairs for their primary means of mobility. Wheelchair users encounter obstacles such as bumps, curb descents, and uneven driving surfaces every day. These obstacles cause vibrations in the wheelchair, and in turn, whole-body vibrations are transferred to the wheelchair user.

Prolonged exposure to whole-body vibrations can cause harmful physiological responses in explicit areas of the body such as the cardiovascular system, central nervous system, and the musculoskeletal system (2), specifically leading to spinal deformities, herniated discs, and chronic low back pain.

The Hybrid III test dummy is the most recent attempt to mimic humans for use in research studies. It was developed by General Motors Corp. in 1990 as a fourth generation test dummy to incorporate high level biomechanical responses (4). Hence, the Hybrid III test dummy represents a good model to measure how whole-body vibrations are transferred to a wheelchair user via the particular wheelchair that they use.

## RESEARCH QUESTION

Manual wheelchair users are subjected to a high level of whole-body vibrations over the course of any ordinary day (6). Wheelchair manufacturers have therefore made an attempt to suppress these vibrations by creating suspension manual wheelchairs. The purpose of this study was to determine if these wheelchairs actually reduce the vibrations experienced by wheelchair users and also to determine if certain types of wheelchairs reduce vibrations better than others.

## METHODS

Five manual wheelchairs were selected for this study. Each of the five wheelchairs was propelled over two obstacles that represent tasks encountered during the everyday activities of a wheelchair user. The two obstacles used were a rumble strip and a 50 mm curb descent (Figure 1), which represent oscillatory vibrations and shock vibrations respectively. Two of these chairs were suspension wheelchairs, the Quickie XTR, which uses a coiled spring shock absorber and the E&J Barracuda, which uses elastomer shock absorbers, two were solid frame wheelchairs, the Quickie GP and the Ti Sports, and the fifth was a folding frame wheelchair, the Kuschall 1000. Each of the wheelchairs used spoked pneumatic tires and solid polyurethane OEM casters and had a seat size of 16 in. x 16 in.

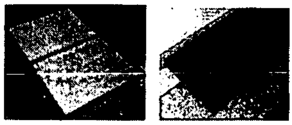

Figure 1
Rumble Strip and Curb Descent

To examine the vibrations that occurred, each of the wheelchairs traversed each of the obstacles ten times. Two triaxial accelerometers were used to collect vibration data from the seat of the wheelchair and to collect the vibrations from the dummy. Each of the trials was conducted at a constant velocity of $0.61 \pm .01$ m/s with no significant difference in the time to conduct each trial. The position of the dummy was also kept constant between trials to maintain repeatability (Figure 2).

Figure 2
Hybrid III Dummy

In order to analyze and compare the effects of vibrations on the different wheelchairs two methods were used. The vibrational dose value (VDV) was used to determine the oscillatory vibrations from the rumble strip, and a peak-to-peak evaluation was used to evaluate the shock vibrations from the curb descent. The VDV is a variation of the root mean squared acceleration for analyzing oscillatory systems. However the VDV is more sensitive to peaks due to the higher order power (eqn. 1). The single power values obtained for each of the wheelchairs can then be statistically compared. To analyze the shock vibrations using the peak-to-peak method, a difference is measured between the maximum peak and the minimum peak when the wheelchair's rear wheels hit the ground. This is an accepted measurement of the acceleration corresponding to the curb descent.

$$VDV = \left\{ \int_0^T [a_w(t)]^4 dt \right\}^{\frac{1}{4}} \quad (1)$$

## RESULTS

Analysis of the data revealed significant differences ($p<0.05$) between the wheelchairs in both the VDVs and the peak-to-peak values at the wheelchair and at the dummy. The only results that showed no significant difference were between the Quickie GP and the E&J Barracuda for the VDVs and the peak-to-peak values at the dummy. Figure 3 shows a graph of the average results and the standard deviations for the VDVs and the peak-to-peak values at the wheelchair and at the dummy.

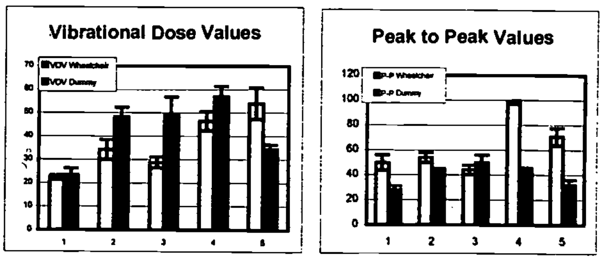


Figure 3. Comparison of Vibrational Dose Values and Peak-to-Peak Values measured at the wheelchair and the dummy of the manual wheelchairs. 1.Quickie XTR 2.Quickie GP 3.Kuschall 1000 4.E&J Barracuda 5.Ti Sports

## DISCUSSION

Multiple studies have shown that there is evidence for an increased risk to health mainly in the lower back and the central nervous system due to long-term exposure to high intensity whole-body vibrations. (5)

The results of this study reveal that there are significant differences ($p<0.05$) between manual wheelchairs and the vibrations that these wheelchairs exhibit while negotiating obstacles. Possible reasons for these differences include the designs of these wheelchairs and also the construction materials

Wheelchair users encounter obstacles like the ones tested in this study and countless other obstructions every day. The vibrations measured were well above the recommended amount required for comfort of a seated individual, as described in ISO 2631-1, although these vibrations were measured for a very short period of time. However, the vibrations measured from the dummy for the XTR and the Ti Sport for the VDV and the peak-to-peak were significantly lower than the other wheelchairs. This result seems to affirm that besides a wheelchair having a suspension system, a titanium frame may absorb the vibrations experienced by the wheelchair before transmission to the user, which has been suggested by some manufacturers. However, the Barracuda, another suspension wheelchair, has a higher VDV for the dummy showing no improvement with the suspension system. The Barracuda showed improvement in dummy shock but was still well above the other suspension wheelchair, the Quickie XTR, and also the Ti Sports.

## CONCLUSION

Wheelchairs that can reduce the amount of vibrations transmitted to the user present a useful solution to harmful whole-body shocks and vibrations. Whole-body vibrations must be minimized to reduce an individual's vulnerability to secondary injuries, such as low-back pain and disc degeneration. Current suspension manual wheelchairs may offer some relief from vibrations but are not ideal. The results from this study could be used to enhance the development of suspension wheelchairs and improve the quality of life of wheelchair users by reducing secondary injuries.

## ACKNOWLEDGEMENTS

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# CHARACTERIZATION OF ELECTRIC POWERED WHEELCHAIR USE IN THE COMMUNITY

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## ABSTRACT
The purpose of this study was to determine the driving characteristics of community dwelling users of electric powered wheelchairs. A datalogger, designed by the laboratory, was used that collected information on the distance traveled per day, average speed while driving, distribution of driving over the day, and distance traveled between battery charges(1). Data were collected from participants in the 20th National Veterans Wheelchair Games (NVWG), San Antonio, Texas and a group of electric powered wheelchairs in Pittsburgh (Pitt), Pennsylvania. This data has important implications for the design of electric powered wheelchairs, and the design and selection of wheelchair batteries.

## INTRODUCTION
There is very little information about the actual driving behavior of users of electric powered wheelchairs. This information is critical to the design of electric powered wheelchairs, wheelchair components, battery design/specification, and in studies of risk exposure (e.g., risk of injury due to component failure). Winyard et al. found that in a survey of 100 electric powered wheelchair users, major modifications to the powered wheelchair were necessary to determine its function and reliability(2). In an interview of 11 current and future electric powered wheelchair users, Miles-Tapping and MacDonald found that for people who experience a traumatic impairment, the decision to use an electric powered wheelchair is simply just one of the many decisions made during rehabilitation, as opposed to people who have progressive disabilities and who draw this decision process out as the individual comes to the realization that this is an entirely new lifestyle(3).

## METHODS
Design and Participants: This was a multi-site engineering evaluation of electric powered wheelchair driving activity during unrestricted community mobility. Seventeen electric powered wheelchair users recruited from the National Veterans Wheelchair Games (NVWG) (n = 10) in San Antonio, TX and from United Cerebral Palsy Association of Allegheny County (Pitt) (n = 7) in Pittsburgh, PA gave informed consent to participate in this study. Subjects included in this study had the following diagnosis': Paraplegia (n=3), Tetraplegia (n=6), Multiple Sclerosis (n=1), Spina Bifida (n=1), Polio (n=1), Muscular Dystrophy (n=1), Head Injury (n=1), Cerebral Palsy (n=2), or Lower Motor Neuron Disease (n=1). The subjects had been using electric powered wheelchairs as their primary means of mobility within the community a mean $\pm$ SD of 14.5 $\pm$ 11.5 years. All of the wheelchairs included in this study were rear wheel drive with front casters and had sealed lead acid batteries.

Instrumentation: A data-logger which was based upon a TFX-11 single board computer (Onset Computer Corporation) was mounted in a shock, tamper, and water resistant box onto each subjects' wheelchair. A ceramic permanent magnet was adhered to the hub or tire and a reed switch was attached to the frame of each wheelchair tested. Each time the magnet passed the reed switch the time was stored to the nearest second. The output of the reed switch was input to a simple passive de-bounce circuit to eliminate erroneous switch closures. Data-logger recordings were down-loaded to a personal computer and data analysis utilized software written in Matlab (The MathWorks, Inc.).

Protocol: Each subject was asked a series of standardized questions to collect descriptive statistics of the wheelchair and wheelchair user. The data-logger and sensor were installed on each subject's personal wheelchair with double sided Velcro™ tape in an unobtrusive location and subjects were instructed to go about their daily activities as usual. Five complete days of data were analyzed.

## RESULTS

The NVWG group traveled faster than the Pitt group, but this difference was only statistically significant on the first day. The NVWG group was more likely to travel longer than the Pitt group with significant differences seen in days 4 (p=0.03) and day 5 (p=0.05). Total distance traveled during the five-day period and average distance traveled per day were also significantly different between the groups (p=0.02 for both 5-day distance and daily-distance), with the NVWG group traveling longer (17164±8708 meters) when compared to the Pitt group (8335±7074 meters) over the five-day period. Both distance traveled and speed increased during daylight hours. The maximum distance traveled by any subject for each hour across the two groups was used to create the theoretical maximum distance day which resulted in 7,970 meters of driving.

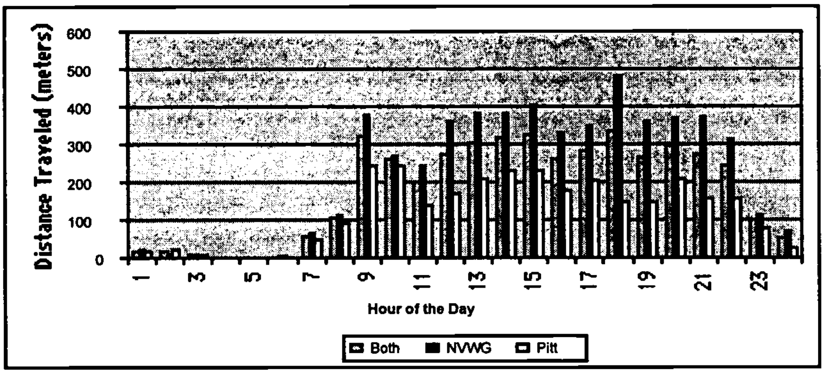


Figure 1: Average Distance Traveled Across 24 Hrs.

## DISCUSSION

We hypothesized that the participants in the National Veterans Wheelchair Games would be more active than a sample of community dwelling drivers of electric powered wheelchair users. We based our hypothesis on the assumption that the large numbers of activities open to the participants, readily available transportation, and the camaraderie among the participants would encourage high activity among users of electric powered wheelchair users. The NVWG group went further and faster than the Pitt group on a daily and five-day basis. The NVWG group went nearly twice as far as the Pitt group over the five day sampling periods. The NVWG group was more active than the Pitt group later into the evening hours, a further indication of the activities available to the NVWG participants. Both groups showed peak of activity (indicated by average hourly speed and average hourly distance) during the afternoon and early evening hours. The maximum speed of each subject's electric powered wheelchair was approximately 2.7 m/s. The subjects drove their wheelchair considerably less than the wheelchair's maximum speed during most of the time. Spurts of speed are likely related to crossing intersections, avoiding pedestrians, and other similar maneuvers. Of course, some of the bouts of near maximum or maximum speed driving were during competition for the NVWG group.

This study provides some of the first data recorded on the actual usage of community dwelling users of electric powered wheelchairs. The results have some important implications for the design and selection of batteries and other potential power sources. Given the information from this study and the energy and power requirements of their wheelchair, a wheelchair manufacturer can select the optimal battery. Future studies should collect data from both drive wheels in order to determine the amount of time spent turning versus going straight. In addition, the sensors need to be modified in order to detect whether the wheelchair is driving forward versus reverse. The addition of an inclinometer would allow including studying the distance driven while negotiating curb-cuts, slopes, and ramps.

## CONCLUSION

Drivers of electric powered wheelchairs are most active during the afternoon and evening hours. The subjects participating in the National Veterans Wheelchair Games were more active than the Pitt group during a typical week at home. However, there was little variation in the speed or distance driven per day. The maximum theoretical distance that a wheelchair user in our group would travel is less than 8 km. The range of current electric powered wheelchair appears adequate for the subjects in our study.

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**List of Suppliers**

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# COMPARISON OF LABORATORY AND ACTUAL FATIGUE LIFE FOR THREE TYPES OF MANUAL WHEELCHAIRS

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## ABSTRACT

Laboratory studies have found that ultralight wheelchairs have a longer fatigue life than lightweight and depot wheelchairs. Actual fatigue life of wheelchairs in a 'real world' setting has never been examined. This study seeks to compare the laboratory fatigue life of wheelchairs results to a 'real world' setting. Through examination of the VA National Prosthetic Patient Database, it is possible to determine the number of wheelchairs that are prescribed and repaired at VA hospitals in a given period of time. Results indicated that the 'real life' data is consistent with the laboratory findings in that depot chairs accounted for the most repairs.

## BACKGROUND

The three most common types of manual wheelchairs are the depot, lightweight, and ultralight varieties of wheelchairs. Previous studies conducted at the Human Engineering Research Laboratories (HERL) have found that ultralight wheelchairs have a longer fatigue life than lightweight wheelchairs, which in turn have a longer fatigue life than depot wheelchairs(1). These studies have all been conducted in a laboratory setting using double-drum and curb-drop testing machines to simulate wheelchair use. However, these findings have never been compared with fatigue life of wheelchairs actually being used by individuals. The examination of two databases, the VA National Prosthetic Patient Database and the Human Engineering Research Laboratories Database, has made it possible to complete comparison studies between laboratory findings at HERL and real life findings.

## METHODS

The Human Engineering Research Laboratories Database contains information on the wheelchairs that have been tested at HERL according to the International Standards Organization (ISO) and the American National Standards Institute and Rehabilitation Engineering and Assistive Technology Society of North America's (ANSI/RESNA) twenty-two wheelchair standards. This database contains information on over 130 different manual and power wheelchairs and electric scooters. For this study, fatigue life data, which is found in Section 8, *Static, Impact and Fatigue Strength Testing* of the standards was primarily used(2). Fatigue life is defined as how long it takes for a wheelchair to no longer serve as a functional mobility device. Laboratory fatigue life is determined by the number of cycles completed on the double drum and curb drop testing machines, and the total number of cycles is found by the following equation, which is based on the ratio for the double-drum cycles and curb-drops in ISO 7176-08(1):

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$$\text{Total Cycles} = (\text{Double-Drum Cycles}) + (30 * \text{Curb-Drop Cycles})$$

The double-drum test machine consists of two drums that a wheelchairs is balanced upon (the drive wheels are placed on one and the casters on the other) that rotate, simulating sidewalk cracks, door thresholds, potholes, and other common road hazards. One cycle is defined as a full rotation of the rear roller. The curb-drop test machine is a device that lifts the wheelchairs five centimeters and allows it to fall onto a hard surface, simulating the common occurrence of going down small curbs[(3)]. In order to comply with ISO standards, a wheelchair must complete 200,000 cycles on the double drum tester and then 6,666 cycles on the curb drop without experiencing a Class III or two of the same Class I or II failures. This is said to simulate three to five years of active wheelchair use[(4)]. A Class III failure describes structural damage that would immobilize the wheelchair. A Class II failure describes minor damage that can be fixed by a repair technician, such as a flat tire. A Class I failure describes a minor adjustment or repair that can be fixed by the wheelchair user or an untrained person, like a loose screw or bolt[(3)]. Data has shown that depots undergo the most Class III failures with Class I and II failures happening more frequently with lightweight and ultralight wheelchairs.[1]

The National Prosthetic Patient Database (NPPD) is a database compiled by the Department of Veterans Affairs, Prosthetic and Sensory Aids Service. This database collects ongoing information on all prosthetics (e.g. wheelchairs, assistive devices, prostheses, eyeglasses, hearing aids) that have been prescribed through the Veterans Health Administration System (VA). The VA is divided into twenty-two Veterans Integrated Service Networks (VISNS). The NPPD database is grouped according to these VISNs. For the purposes of this pilot study, we have used information from October of 1998 through September of 1999 and analyzed data from three of the VISNs. In addition, we used the wheelchair entries from the database.

A comparison was made between fatigue life found in a laboratory setting of three categories of wheelchairs and the fatigue of similar wheelchairs in their first year of use by actual wheelchair users. The three types of wheelchairs analyzed were depot, lightweight, and ultralight wheelchairs. A depot wheelchair is defined as a wheelchair with a Healthcare Finance Administration Common Coding Procedure Coding System (HCPCS) code of K0001, K0002, or K0003. These chairs are primarily designed for temporary institutional use and are not meant as long-term mobility devices[(3)]. A lightweight wheelchair is defined as a wheelchair with a HCFA coding of K0004. These chairs weigh less than depot chairs and are more adjustable and adaptable to patients' needs[(1)]. The final type of wheelchair is an ultralight wheelchair, with a HCFA coding of K0005. Ultralight wheelchairs are the lightest and most adaptable of manual wheelchairs[(1)]

**RESULTS**

Preliminary findings indicate that 2292 basic manual wheelchairs were issued in the three VISNs. Of these, 1398 (61.0%) were depot chairs, 742 (32.4%) were lightweight chairs, and 152 (6.6%) were ultralight chairs. A total of 1191 wheelchair repairs were completed during the same time span. These numbers represent the total number wheelchairs issued or repaired, compared to wheelchairs that were issued or repaired per veteran of the VA. Table 1 shows the breakdown of the number of veteran's wheelchairs that were repaired and the number of repairs that were completed.

Table 1: Number of repairs in 1998 for three VA VISNS

| Wheelchair Type | Vetrean's Wheelchair Repaired n (%) | 1 repair n (%) | ≥ 2 repairs n (%) | Total # of repairs n (%) |
|---|---|---|---|---|
| Ultralight | 115 (17.7) | 46 (40.0) | 69 (60.0) | 207 (23.6) |
| Lightweight | 141 (27.7) | 53 (37.6) | 89 (63.4) | 185 (21.1) |
| Depot | 393 (60.6) | 288 (73.3) | 105 (26.7) | 484 (55.3) |

As can be seen, 649 veterans had wheelchairs that needed to be repaired with 876 total repairs completed. Sixty percent of the veterans who needed repairs on their wheelchairs, owned depots. Most of the depots only required 1 repair, where as the ultralights and lightweights were more likely to have multiple repairs. At this time, specific information on the type of repair is not reported, so it is possible that the repairs are minor for the ultralight and lightweight wheelchairs and more serious repairs with the depots.

## DISCUSSION

Previous studies conducted at HERL have found that ultralight wheelchairs have the longest fatigue life of the three types of manual chairs, lasting 13.2 times longer than depot chairs(4), and that they are the most cost-effective, costing 3.4 times less per life cycle than depot chairs, but that they are the most likely to experience a Class I failure(1). The 'real life' data is consistent between the laboratory and actual findings with depot chairs accounting for the most repairs. With further examination of the data it will be possible to determine the extent of the repair by cost and whether the wheelchairs was replaced. The NPPD Database reflects only one year of wheelchair use while the fatigue tests conducted at HERL are designed to simulate the wheelchair's full life. This study is only in its preliminary stages and the results are not conclusive, as only three of the 22 VISNS are presented.

## ACKNOWLEGDEMENTS

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# USING STABILITY AND FATIGUE STRENGTH TESTING WHEN CHOOSING A MANUAL WHEELCHAIR

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## ABSTRACT

The purpose of this study was to explain how the static stability and fatigue strength sections of the ANSI/RESNA Wheelchair Standards can be used to determine important differences between wheelchairs. Sections 1 and 8 were analyzed for several different manual wheelchairs. The results show that many wheelchairs differ in performance. Thirty wheelchairs were tested for static stability. The range between the minimum and maximum tipping angles was 27 degrees. Forty-one percent of the 46 wheelchairs tested for fatigue strength failed to pass the minimum requirements. Seventy-four percent of the 38 wheelchairs tested until failure experienced some type of frame failure. Knowing the characteristics of a given wheelchair will allow people to choose the safest and most practical design for their needs.

## INTRODUCTION

Many wheelchairs may look the same, but most of them have very different performance characteristics. Being informed about wheelchairs and how they perform can help people choose safer and more practical devices for their own use. HERL has tested over one hundred power and manual wheelchairs. This paper will help demonstrate the differences in stability and fatigue strength that exist between wheelchairs that may not be obvious to the consumer without the use of ANSI/RESNA Wheelchair Standards.

Static stability and fatigue strength are two of the most important and informative tests in the standards. Knowing the tipping angle and expected life of a wheelchair can lead to safer use by the consumer. The FDA utilizes the ANSI/RESNA Standards to determine whether wheelchairs are safe and reliable. Consumers can also use the standards to find a wheelchair that is best suited for their particular lifestyle.

## METHODS

ANSI/RESNA Wheelchair Standards were used to test each of the manual wheelchairs. Sections 1 and 8 were evaluated for manual wheelchairs. Section 1 is a test of static stability for wheelchairs. Every wheelchair is tested facing uphill, downhill, and sideways.

Section 8 is a test for static, impact, and fatigue strength. This study was only concerned with the results for fatigue strength testing. Every wheelchair was placed on a two-drum machine and run for 200,000 cycles at a speed of 1m/s. If the wheelchair completed the two-drum test, then it was placed on the curb drop machine for 6,666 cycles. Many of the wheelchairs were then continuously cycled through these two tests until failure.

## RESULTS

Thirty manual wheelchairs were tested for static stability. Table 1 shows the range of different values for each stability test.

Table 1

| | # Of Wheelchairs | Average Angle (sd) | Max. Angle | Min. Angle |
|---|---|---|---|---|
| Uphill | 30 | 11.6° (2.3°) | 15° | 8° |
| Downhill | 30 | 22.2° (4.8°) | 40° | 13° |
| Lateral | 30 | 19.3° (2.2°) | 23° | 14° |

Forty-six manual wheelchairs were tested for fatigue strength. Nineteen of the 46 manual wheelchairs failed the fatigue strength testing. Table 2 lists the failures as well as the minimum, maximum, and average number of cycles completed by these wheelchairs.

Table 2

| | # Of Failures | Avg. Cycles (sd) | Max. Cycles | Min. Cycles |
|---|---|---|---|---|
| Double-Drum | 16 | 134969 (50766) | 200000 | 59539 |
| Curb Drop | 3 | 5526 (1975) | 6666 | 3245 |

Thirty-eight of the manual wheelchairs were tested until failure. Table 3 shows the minimum, maximum, and average number of cycles until failure.

Table 3

| | # Of Wheelchairs | Avg. Cycles (sd) | Max. Cycles | Min. Cycles |
|---|---|---|---|---|
| Double-Drum | 38 | 392537 (337789) | 1200000 | 59539 |
| Curb Drop | 22 | 17164 (12217) | 39996 | 3245 |

Twenty-eight of the 38 wheelchairs tested until failure experienced a frame failure. Table 4 lists the minimum, maximum, and average number of cycles until failure.

Table 4

| | # Of Wheelchairs | Avg. Cycles (sd) | Max. Cycles | Min. Cycles |
|---|---|---|---|---|
| Double-Drum | 28 | 297722 (271278) | 1000000 | 59539 |
| Curb Drop | 13 | 14304 (9590) | 33330 | 3245 |

**DISCUSSION**

The results from static stability testing show that there is a large range of tipping angles. The minimum and maximum downhill tipping angles differ by 27°. The type of wheelchair and set-up determine what the tipping angles will be. Tips and falls are perhaps the greatest concern with wheelchair safety. Gaal et al found that of 253 reported wheelchair incidents, 42% comprised of tips and falls (2). Ummat and Kirby found that of 2,066 nonfatal wheelchair-related accidents reported to the National Electronic Injury Surveillance System, 73.2% involved falls and tips (3). Differences in tipping angles cannot only occur between two different wheelchairs, but also between different settings of the same wheelchair. Adjusting different components on a wheelchair can alter the stability significantly.

The results from fatigue strength testing show that some wheelchairs experience catastrophic failures at very low cycles. Forty-one percent of the wheelchairs in this study failed to complete 200,000 cycles on the two-drum and 6,666 cycles on the curb-drop. This is a very important aspect for active wheelchair users to consider. People who are active outdoors tend to put increased stresses on their wheelchairs due to curbs and other obstacles (4).

Almost 74% of the wheelchairs that were tested to failure experienced a frame failure. These failures had a lower number of average two-drum cycles (297,722) than the wheelchairs that failed due to another reason (658,018). The type of material that a frame is made of can greatly affect its fatigue life. Titanium and fiber composites can reduce a wheelchair's weight while

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providing added strength. Lower end wheelchairs will usually incorporate low grade steel or aluminum that will reduce the cost of the wheelchair, but also decrease its fatigue life.

Section 8 is also useful for determining what the expected maintenance will be for a wheelchair. During fatigue strength testing, many wheelchairs experience class I or II failures. These failures are considered maintenance issues that can be easily fixed by the user or dealer. The wheelchair does not fail the test unless it experiences three of the same class I or II failures. However, consumers should be aware of the amount of maintenance that may be necessary for their wheelchair. A very active outdoor user may not want to select a wheelchair that has a history of caster bolt failures. Fitzgerald et al found that in a study involving 61 manual wheelchairs, there were 21 class I failures and 29 class II failures (5).

Cost analysis is another benefit that can be determined from fatigue testing. Studies at HERL have shown that certain wheelchairs may have a higher initial cost than others, but because they last longer, they end up saving the user money in the long run. Consumers should examine the fatigue life and cycles/dollar of a wheelchair, not just the overall price. A study by Cooper et al found that rehabilitation wheelchairs lasted significantly longer than depot wheelchairs and thus had a lower cost per cycle (6). The rehabilitation wheelchairs lasted 13.2 times longer than the depot wheelchairs, which cost 3.4 times as much to operate per cycle.

## CONCLUSION

The results mentioned above have a significant impact on the user. All wheelchairs are different and must be evaluated based on performance and safety.

Stability is perhaps the most important safety issue related to manual wheelchairs. The ANSI/RESNA Standards determine the tipping range of wheelchairs and help users choose a set-up that is functional yet safe. Results analyzed from fatigue testing provide information about the life cycle and cost analysis of manual wheelchairs.

This paper only addressed sections 1 and 8 of the standards. However, it should be noted that all sections of the standards provide significant information about wheelchairs. The more information that a consumer possesses, the better chance that he/she will choose the wheelchair that best fits his/her lifestyle.

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# QUANTIFICATION OF FORCES ASSOCIATED WITH EPISODIC FULL BODY EXTENSOR SPASTICITY IN CHILDREN

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## ABSTRACT

This study was designed to investigate the characteristics of episodic extensor spasticity in terms of peak seat back force and force-time history. This information is needed to guide the design of dynamic wheelchair seating systems. An ultra-light force sensing array mat was used to gather data on the magnitude, location and force-time characteristics being exerted on the seat back during extensor spasticity episodes. 18 children between the ages of 5 and 16 years were evaluated. 15 of the subjects were diagnosed with Cerebral Palsy, 2 were diagnosed with Lesch-Nyhan and 1 with Glutaric Aciduria. The FSA mat was placed between the subject and the seat back panel of his/her system. Auditory and visual stimuli were provided to facilitate extension. Peak force produced during extension ranged from 18.9 lbs. to 236.1 lbs. with a mean of 92.3 ± 61.5 lbs. Peak torque values ranged from 13.9 ft-lbs. to 227.0 ft-lbs. with a mean of 80.4 ± 58.9 ft-lbs. The peak vertical centers of pressure ranged between 8.0 in and 19.7 in above the level of the seat. Despite the artificial ceiling imposed by the FSA mat in measuring the maximal amount of force exerted on the seatback, this study provided preliminary data for the development of an instrumented laboratory dynamic seating system.

## BACKGROUND

Attempts at changing, controlling, inhibiting or normalizing atypical movement patterns continue to be the goal of many health care providers working with individuals who present with movement disorders. Incorporating treatment strategies to help achieve the desired functional outcome requires knowledge of the characteristics of the behavior. This project is a pilot study designed to investigate the force generated in episodic increases in extensor spasticity. This study proposes to quantify key characteristics of the event for future studies focused on the development of an instrumented laboratory dynamic seating system to further characterize extensor spasticity.

## RESEARCH QUESTION/OBJECTIVE

The question to be answered by this study is "What are the characteristics of episodic full-body extension events?" The data analyzed will include peak total force, peak seat back torque, and force distribution. This preliminary data will be used to guide the design of a prototype laboratory dynamic seating assessment device for future studies.

## METHOD

The subject population consisted of 18 children with a history of extensor thrusting events. Their ages ranged from 5 to 16 years with a mean age of 10.5 ± 2.6 years. The primary criterion for inclusion in the study was a history of episodic full-body extension. The only children excluded from the study were those who were receiving intrathecal baclofen treatments. The primary diagnosis of 15 of the subjects was Cerebral Palsy. 3 subjects were diagnosed with metabolic disorders, including 2 with Lesch-Nyhan and 1 with Glutaric Aciduria.

QUANTIFICATION OF FORCES

Subjects were seated in their own postural support systems with a forced sensing array (FSA) mat placed posteriorly between the trunk and back panel of the seating system (Figure 1). The ultra thin FSA seat model that has a 16 x 16 - row column sensor arrangement was used for this study. There are a total of 256 sensors that can be calibrated through a pressure range of 0 – 200 mmHg. FSAWIN software was run on an IBM compatible computer and was used to collect and process the data. All subjects were seen once to collect the following data: (1) body weight, (2) wheelchair dimensions, (3) seated postural measures of the subject, (4) peak seat back force, and (5) seat back force-time history. Data from the FSA mat was collected over a 30-minute period of time while subjects were exposed to a taped air horn sound burst in an attempt to elicit an extension episode. The sound stimulus occurred 5, 15 and 25 minutes after FSA data collection began.

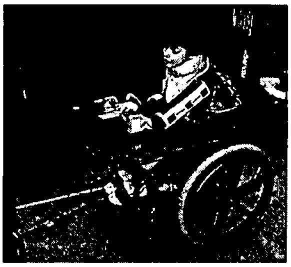

Figure 1:
7-year-old male subject seated in a Quickie LX manual wheelchair with the FSA mat placed on the seatback. The subject has bilateral elbow splints to prevent self-mutilation of his upper extremities.

## RESULTS

There was a minimal reaction of the subjects to three pre-recorded sound burst intended to facilitate full-body extension. Ranges of peak total force, peak seat back torque, area of contact, and location of center of pressure were analyzed for each subject (table 1).

Table 1- Individual subject data

| Subject | Peak Total Force (lbs.) | Peak Torque (ft-lbs.) | Peak $COP_h$ (in) | Peak $COP_v$ (in) | Maximum Area of Contact ($in^2$) |
|---|---|---|---|---|---|
| Subject 1 | 133.1 | 119.8 | 13.9 | 19.7 | 231.3 |
| Subject 2 | 158.6 | 89.4 | 13.4 | 8.0 | 132 |
| Subject 3 | 85.4 | 73.2 | 18.6 | 12.4 | 133.2 |
| Subject 4 | 236.1 | 181.6 | 16.7 | 15.8 | 198.6 |
| Subject 5 | 142.4 | 133.7 | 12.9 | 17.4 | 203.4 |
| Subject 6 | 94.9 | 93.5 | 18.2 | 18.5 | 88.4 |
| Subject 7 | 187.9 | 227.0 | 17.3 | 15.9 | 197.4 |
| Subject 8 | 34.4 | 28.2 | 15.7 | 10.6 | 131.9 |
| Subject 9 | 58.8 | 40.9 | 12.3 | 13.2 | 141.7 |
| Subject 10 | 29.1 | 13.9 | 13.4 | 15.4 | 127.2 |
| Subject 11 | 75.6 | 75.1 | 16.5 | 14.5 | 142.8 |
| Subject 12 | 47.3 | 44.7 | 18.4 | 14.3 | 132 |
| Subject 13 | 60.8 | 39.8 | 11.4 | 12.5 | 142.9 |
| Subject 14 | 77.1 | 106.4 | 12.1 | 17.1 | 99.3 |
| Subject 15 | 45.9 | 31.7 | 14.8 | 13.5 | 93.2 |
| Subject 16 | 142.9 | 106.7 | 13.9 | 13.5 | 235.1 |
| Subject 17 | 18.9 | 16.5 | 18.6 | 15.9 | 109.0 |
| Subject 18 | 31.3 | 25.9 | 18.6 | 15.3 | 41.2 |

Peak total forces for the group ranged from 18.9 to 236.1lbs. with a mean of 92.3 ± 61.5 lbs. The vertical center of pressure ($COP_v$) ranged from 7.9 inches to 19.7 inches above level of the seat plane with a mean of 14.6 ± 2.8 inches. Peak torque values were calculated as the product of the maximum $COP_v$ times the peak force. Peak torque ranged from 13.9 ft-pounds to 227.0 ft-pounds with a mean of 80.4 ± 58.9 ft-lbs. Maximum area of contact ranged from 41.2 in$^2$ to 235 in$^2$ with a mean of 143.0 ± 51.9 in$^2$. The horizontal center of pressure ($COP_h$) ranged from 11.4 inches to 18.6 inches across the seat back. The $COP_h$ mean was 15.4 ± 2.6 inches from the back cane. Maximal extension events lasted from 1.7 seconds to 4 minutes 33.1 seconds with a mean of 1 minute 29.9 seconds.

## DISCUSSION

The maximum pressure that each sensor of the FSA mat can accurately measure is 200 mmHg, which is approximately 4.7 pounds per sensor producing a ceiling effect for 14 of the 18 subjects; a major limiting factor of this study. Over a one-half hour period of time, the number of sensors that registered this false peak ranged from less than 0.1% to 98%. Of the remaining 4 subjects unaffected by the false ceiling, 2 reached a maximum of 4.6 pounds per sensor and 1 each peaked at 4.2 and 3.6 pounds per sensor. The number of sensors registering at peak values among these 4 subjects ranged from less than 0.1% to 0.5%.

Another problem encountered was that the size of the mat was larger than the seat back panels of the seating systems. This set-up permitted movement of the mat, potentially effecting the location of both the vertical and horizontal centers of pressure.

Another factor to be considered was that it was assumed that by using a loud sound, an auditory startle could progress into an extension event however, this was not true in many cases. It is believed that one possible reason why subjects did not respond to the stimulus was that it was not loud enough. Koch [1] stated that an auditory startle is elicited at > 80 decibel (dB) sound pressure level (SPL). The SPL of the facilitating stimulus in this study was not measured but the recorded air horn blast is estimated at much less than 80 dB.

## CONCLUSION

It is necessary to learn about a behavior before attempting to change or modify it. We are still characterizing atypical muscle tone and the variety of behaviors that individuals manifest as a result of it. Despite the fact that 14 of the 18 subjects were limited in the force that could be measured by the FSA mat, this study provides a starting point from which to begin observing episodic extensor spasticity in the seated child. This study also provided pilot data for use as input to a computer simulation based design of an instrumented laboratory dynamic seating system.

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# LONG-TERM MONITORING OF WHEELCHAIR USAGE WITH AND WITHOUT THE YAMAHA JWII POWER ASSISTED WHEELCHAIR HUBS

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## ABSTRACT

Seven manual wheelchair users used JWII power assisted wheelchair hubs for two weeks. Their usage was monitored through a datalogger and questionnaires, and compared with their own devices. Velocity, ease of propulsion and riding comfort ratings, and the number of times people went out showed no significant differences. Excluding immobile hours, subjects propelled more distance per hour with JWII. While JWII does not seem to change patterns of daily activity, it seems to encourage mobility especially for people with upper extremity injuries. Subjects enjoyed the JWII's ability to manage rough terrain and uphill as well as the high speed. User comments suggest that some improvement of the hardware design is necessary.

## BACKGROUND

Research regarding secondary disabilities of manual wheelchair users (MWU) provokes attention; there are many upper extremity injuries associated with everyday propulsion (1). Among other alternative designs, the JWII pushrim activated power assisted wheelchair hubs (PAPAW) have been developed in order to decrease the prevalence of these injuries. Earlier publications show that the JWII hubs comply with ANSI/RESNA standards, decrease the demand of metabolic energy (2), increase gross mechanical efficiency (3) and decrease stroke excursion (4).

## RESEARCH QUESTION

This study was conducted to evaluate the JWII PAPAW in users' real life settings in order to compare quantitative and qualitative data on people's activities of daily living patters with traditional manual wheelchairs.

## METHOD

Five male and two female manual wheelchair users participated in this study. Average age was 42.1 +/- 8.3 years and time post injury 14.8 +/-6.6 years. Six individuals had a history of upper extremity trauma. Subjects used a Quickie frame with JWII hubs for two weeks as their primary mean of mobility. Their usage of the PAPAW was monitored and compared with two weeks' usage of their personal wheelchairs. All subjects gave their informed consent prior to participating in the study.

A commercially available datalogger was modified (5) and placed on the wheelchairs for continuous data recording. Two magnets, 180 degrees apart were placed on the spokes. Every time a magnet passed the reedswitch, which was placed on the frame, a signal was sent to the datalogger, which in turn recorded the exact time in seconds' resolution. Total distance, distance per day, distance per hour, maximum and average velocities were calculated from this data using a custom-written Matlab program. Data was downloaded on a weekly basis.

Weekly activity questionnaires complemented the data collection, in addition to first visit and JWII-specific questionnaires. Through these questionnaires, the number of times people went out of their homes, ease of propulsion and riding comfort ratings, as well as subjects' opinion of the JWII could be determined.

The order of wheelchairs was randomized. When using the power assisted device, numerous adjustments were made to comfort users with the new frame (seat width and depth, backrest height, sideguards, armrests, legrests, etc.). All subjects used their own cushion.

Matlab, Excel and SPSS software were used for data analysis. Distributions of all data were examined. Wilcoxon signed ranks test was used where the data was not normally distributed, and Paired T-test was used for normal distribution.

## RESULTS

Results are shown in Table 2. No significant differences ($p>0.05$) were found in either variables of interest. Average distance per day (which includes hours of immobility) is slightly higher with personal wheelchair, while subjective ratings and the number of times subjects went out are higher with the JWII.

| Subject | Avg. distance (m/day) | | No of rainy days | | comfort rating | | ease of propelling | | # of times went out | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Own W/C | JWII | Own W/C | JWII | Own W/C | JWII | Own W/C | JWII | Own W/C | JWII |
| 1 | 715.35 | 1348.7 | 9 | 3 | 4.2 | 8.6 | 4.7 | 8.9 | 3 | 13 |
| 2 | 2800 | 2232 | 6 | 4 | 10 | 9 | 9.8 | 8.8 | 19 | 19 |
| 3 | 1928 | 1096 | 6 | 6 | 6.9 | 7.2 | 6.7 | 6.9 | 20 | 19 |
| 4 | 984 | 1928 | 4 | 8 | 3.9 | 8.4 | 0.5 | 9 | 11 | 56 |
| 5 | 1568 | 1872 | 5 | 7 | 8.8 | 6.8 | 8.9 | 9.1 | 14 | 60 |
| 6 | 1816 | 1920 | 4 | 7 | 4.1 | 9.3 | 3.4 | 9.5 | 31 | 34 |
| 7 | 1584 | 808 | 6 | 4 | 7.6 | 8.2 | 7.5 | 9.4 | 18 | 15 |
| Mean | 1627.9 | 1600.7 | 5.71 | 5.57 | 6.5 | 8.2 | 5.9 | 8.8 | 16.6 | 30.8 |
| SD | 677.26 | 520.86 | 1.7 | 1.9 | 2.5 | 3.3 | 0.9 | 0.8 | 8.6 | 19.7 |
| p | 0.922 | | 0.917 | | 0.237 | | 0.063 | | 0.132 | |

*Table 1. Results from datalogger and questionnaires*

Table 2 displays that average velocity was somewhat higher, while maximum velocity somewhat lower with personal wheelchair. On an average, subjects had positive opinion about the power assisted device. Users enjoyed PAPAW's ability to manage rough terrain and uphill as well as the high speed. The major disadvantages were weight, size, location of battery and difficulty of assembly.

| Subject | Average velocity (m/s) | | Maximum velocity (m/s) | |
|---|---|---|---|---|
| | Own | PAPAW | Own | PAPAW |
| 1 | 0.27 | 0.48 | 2.49 | 2.16 |
| 3 | 0.57 | 0.47 | 2.75 | 2.33 |
| 4 | 0.48 | 0.46 | 2.25 | 1.75 |
| 5 | 0.69 | 0.50 | 2.33 | 2.33 |
| 6 | 0.49 | 0.45 | 2.25 | 2.99 |
| 7 | 0.39 | 0.44 | 1.75 | 1.75 |
| 8 | 0.44 | 0.28 | 1.75 | 2.33 |
| Mean | 0.47 | 0.44 | 2.22 | 2.23 |
| SD | 0.13 | 0.07 | 0.36 | 0.42 |
| p | 0.519 | | 0.958 | |

*Table 2. Average and maximum velocities.*

A typical day, averaged across all users and all trial days is displayed on Figure 1. Peak hours of usage were in the afternoon hours for both wheelchairs. Excluding all immobile hours, JWII shows higher distance per hour results.

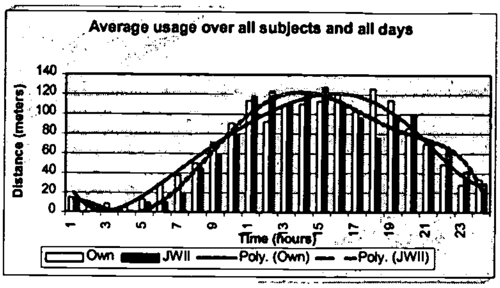


*Figure 1. A typical usage day, averaged across all subjects and all days.*

## DISCUSSION

Due to occasional size and weight problems, not all subjects used the JWII at all times. This may account for the results in Table 1, which are based on values that include zero activity periods. When excluding these immobile times, JWII shows higher results. As for the velocity values not being significantly different, there may be several reasons; 1., JWII adds breaking power downhill, so own wheelchairs may be faster downhill, 2., subjects often had to switch the power off in their homes because JWII would have been too sensitive and fast, but without the power on the device is heavier and slower than own wheelchair, 3., discrete nature of the velocity data warns to caution when drawing conclusions.

Results suggest that people do not significantly change their daily patterns due to a different mobility device. A different wheelchair also takes time to get used to, and potentially longer than two weeks. Subjects' general impression was that the JWII breaks down many barriers, but some improvement of the hardware design is necessary. Further studies identifying potential user groups and quantifying the benefits of PAPAW would be beneficial.

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# A VIDEO-BASED ANALYSIS OF "TIPS AND FALLS" DURING ELECTRIC POWERED WHEELCHAIR DRIVING

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## ABSTRACT

Each year over 36,000 wheelchair-related accidents will cause injury to the wheelchair user. Most of these accidents will be attributed to tips and falls. The purpose of this investigation was to determine if seatbelt use and proper legrest adjustment decreases the frequency and severity of electric powered wheelchair (EPW) tips and falls. The response of a test dummy was video-taped while driving over commonly encountered obstacles and varying legrest height and seatbelt use. No tips, three falls, and several loss of control scores were recorded by two independent reviewers. Seatbelt use and proper legrest height offers greater safety to the EPW user, however, adverse events occur despite their proper use.

## INTRODUCTION

In the United States, an average of 36,559 wheelchair-related accidents each year are serious enough to require the user to seek attention in an emergency room (1). In addition, an average of 51 deaths are caused by wheelchair-related accidents each year (2). Between 1973 and 1987, there were 770 wheelchair-related deaths reported to the United States Consumer Product Safety Commission (USCPSC), 68.5% of which were attributed to falls and tips (2). Of the 2,066 non-fatal accidents reported between 1986 and 1990 to the USCPSC, falls and tips were the cause 73.2% of the time (1). An estimated 24.6% of wheelchair-related accidents involve EPWs (3).

Users of EPWs often have difficulty maintaining a supported seated posture when subjected to external forces (4). These external forces can be induced by ordinary obstacles which an EPW user encounters everyday thus exposing them to the risk of falling from the EPW or completely tipping the EPW. Further increasing the risk to EPW users is the lack of seatbelt use and/or the use of improperly adjusted legrests.

With the incidence of tips and falls in the EPW population, there is a need to characterize the cause of these adverse events. The purpose of this investigation was to qualitatively measure the response/motion of a test dummy while traversing common obstacles encountered by EPW users to determine if optimal wheelchair fit and the use of seatbelts decreases the frequency and severity of EPW tips and falls.

## METHODS

*Test Dummy.* A 50$^{th}$ percentile anthropometric Hybrid II test dummy (HTD) was used to simulate a person driving an EPW. This HTD has been used in previous studies of wheelchair stability and has been shown to emulate a subject with T8 paraplegia caused by traumatic spinal cord injury (4). The HTD was clothed to provide proper seat friction and was checked for proper starting position prior to each data collection trial.

*Test Wheelchairs.* Four different EPWs were evaluated in this investigation: The Quickie P100, the Quickie P200 (Sunrise Medical Inc.), the Action Storm (Invacare Corp.), and the Jazzy 1100 (Pride Mobility). These manufacturers are among the largest in the world. Seating dimensions and backrest angle of all EPWs were consistent. The Jazzy 1100 is equipped with its own seating system and was used for testing. A 50 mm linear foam cushion was used as the cushion of the other EPWs. Tires were inflated to rated pressure and the batteries were charged to at least 75% prior to each data collection period. The EPWs were calibrated to a maximum speed of one m/s while driving on a level tile surface and were operated via a radio control model airplane controller (Figure 1). Speed was verified pre and post-obstacle driving.

*Test Obstacles.* (Figure 2) The EPWs were driven over four commonly encountered obstacles: A door threshold (12mm high x 100mm long x 900mm wide), a standard ADA curb-cut, a five-degree ramp, and a 50mm curb. The curb-cut, ramp, and curb were tested in both ascending and descending conditions. Additionally, the curb was addressed perpendicularly as well as at an approximate 45 degree angle.

*Test Protocol.* To assess the fit of the EPW and the use of seatbelts each obstacle was traversed with and without a seatbelt with the legrests adjusted properly, with the legrests too high, with the legrests too low, and without the legrests. For the purposes of this study, properly adjusted legrests allowed the feet of the HTD to rest flat on the footrests with the thighs of the HTD within +/- 5° of the seat angle. Legrests too high was defined as a gap of 10 to 20mm between the bottom of the HTD thigh and the front edge of the seat cushion. Legrests too low was defined as the point where only the balls of the HTD feet touched the footrests.

Each EPW with the HTD was driven over each obstacle for each condition three times for a total of 216 trials per EPW. All trials were video-taped (Sony Video 8, video camera recorder) at an offset angle approximately 30 degrees from the plane of action. The videotapes were then reviewed and scored on an ordinal/nominal scale. The two reviewers, therapists involved in wheelchair research and prescription, independently viewed the videotapes and recorded an "N" for no fall, an "L" for loss of control (e.g., The HTD falls forward or sideways but remains in chair), an "F" for fall, and a "T" for a complete tip of the EPW for each trial.

Fig.1 HTD, remote control, and door threshold

*Statistical Analysis.* The qualitative response of the HTD recorded by the reviewers was checked for inter-rater reliability using the kappa measurement of agreement.

## RESULTS

The results of the statistical analysis indicate excellent agreement between the two reviewers. Ninety-six percent of the 260 kappa values computed were valued at one (1.0), the greatest attainable agreement value allowed by the kappa measurement.

The reviewers noted only three "falls" of the HTD and no "tips" of the EPW for all conditions and obstacles tested. However, several "loss of control" scores were recorded for the Quickie P100, P200, and the Action Storm for both the upward ramp to flat transition and perpendicular curb descent trials. The "loss of control" scores were associated with both belted and non-belted trials as well as all legrest heights. The Jazzy 1100 received "no fall" scores for all trials from both reviewers.

## DISCUSSION

Although anecdotal, several responses of the HTD to the obstacles were noted. Many non-belted trials resulted in approximately 70-90mm of forward horizontal translation of the HTD. This response was found to occur over all obstacles in all EPWs tested. Greater amounts of translation were associated with improperly adjusted legrests or no legrest situations.

HTD trunk flexion was noted to occur in two obstacle driving situations in three of the EPWs. The Action Storm, Quickie P200, and Quickie P100 were associated with approximately 45 degrees of trunk flexion at upward ramp to flat transition and during perpendicular curb descent resulting in a "loss of control" score. This trunk flexion occurred despite the use of properly adjusted legrests and the use of seatbelts for the Action Storm and Quickie P200. The high degree of trunk flexion is important when considering an individual with a high spinal cord lesion and greater impairment of trunk musculature control.

Figure 2. Test Obstacles

50 mm curb Curb Cut ADA Ramp

## CONCLUSION

This investigation demonstrates that proper legrest adjustment and seatbelt use offers the EPW user greater safety when traversing common obstacles. However, proper use of these devices does not guarantee lesser risk of injury in all EPWs. The fact that "loss of control" can occur despite proper legrest fit and seatbelt use may indicate that proper wheelchair prescription should include an obstacle driving course to ensure the safety and comfort of the EPW user.

The fact that no "tips" of any EPW and only three "falls" of the HTD were recorded in this study implies that faster speeds and conditions such as reverse driving and driving surface angle/tilt should be further investigated. Results from these studies may help to further explain previous epidemiological findings.

## ACKNOWLEDGEMENTS

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# A BREAKTHROUGH IN WHEELCHAIR TECHNOLOGY: A MODULAR BACKREST WITH DYNAMIC CUSHIONING

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## ABSTRACT

Sitting for prolonged periods on a poorly designed backrest causes uncomfortable pressure, eventually leading to open sores, and painful, expensive, medical procedures. To prevent this breakdown a comfortable design was envisioned that distributed the loads, enhanced airflow, had wide adjustment, and was cheap and easy to fabricate. Working closely with our primary customer, Mike Gerhardt, we developed a modular design with multiple axes of adjustment and a novel "floating" pad. The implementation of this design concept uses a configurable depth aluminum bar connected to multiple rotating pads under a cloth covered foam pad, allowing the pads to literally float over the bar. Mike and our other customers are enthusiastic about this prototype and see a viable market compared with the expensive, minimally adjustable, alternatives.

## BACKGROUND

Prolonged sitting in a chair can cause a variety of problems, as seen by the recent study on health issues related to long-duration airplane travel (1). While most people can limit the time they spend sitting, people who have to rely on wheelchairs to get around do not have this choice. There currently is a wide range of products for both the wheelchair seat and back that ease the problems related to long-term usage, but they tend to be costly, not easily customizable, and complex in fabrication.

One significant problem related to long-term use of wheelchairs is the development of pressure sores (caused by high point pressure, heat, and friction). Some type of dynamic damping or hinging is necessary to distribute the shock of the force from moving into the chair or forward motion of the chair. Currently, this damping is only achieved through cloth backs or foam on top of hard backs.

## STATEMENT OF THE PROBLEM

The goal of this project was to create a low-cost, multi-adjustable, back support for collapsible wheelchairs. From this, we developed a set of questions and found a group of wheelchair users to interview. We conducted a series of interviews within this framework to determine a set of customer needs that our device would satisfy. From these interviews, we created the following requirements:

- **Must:** good back support, easily adjustable, secure adjustability, simple, lightweight, high durability, meet testing standards.
- **Should:** good lateral support, adjusts quickly, no gap in seat, not bulky, portable, low cost, material breathability.

## DEVELOPMENT

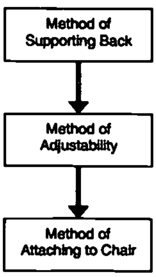

Figure 1: Design Flow

The development of the floating backrest followed the steps outlined in Otto and Wood (2). Based on the interview results, we determined that there were three aspects to this design problem: method of supporting back, method of providing adjustability, method of attaching to the chair. The nature of this problem required that each issue be reviewed individually in a specific order, as the method of attaching to the chair is dependent on the method of providing adjustability which is dependent on the method of supporting the back.

Our initial design was the result of several formalized brainstorming sessions on the topic "Support back well," which led to five different designs concepts that were then refined and evaluated by the team. In order to score each design, we compared them to a product currently on the market (the Jay 2 Back). From the screening we made further refinements to the designs and reviewed them with our primary customer, Mike Gerhardt. A final selection was then made leading to the concept shown in Figure 2.

The alpha design based on this selection consisted of a multiple bar system which would have pads attached through pad arms that could be placed in various locations on the bar. Each bar would be independently adjustable along the chair rods. The variety of pads and locations would provide a customized fit. The bar would fit into connectors, which are fastened to the chair arms without modifications required to the wheelchair. This would allow the rod/pad combination to be removed to fold the chair, if necessary. A fiberglass c-channel was used for the bar, with the pad arms attached to the back as seen in Figure 3. This would allow the channel to dynamically flex open during maximum loads, such as when the user moves into the wheelchair, thereby reducing the force placed on the user's back.

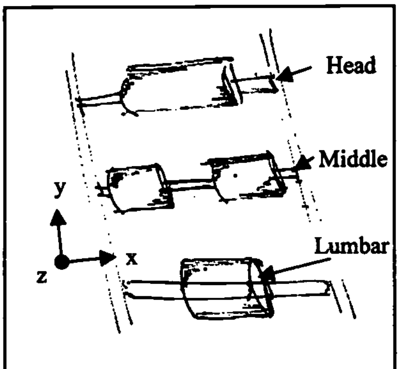


Figure 2
Floating back design: three-bar system

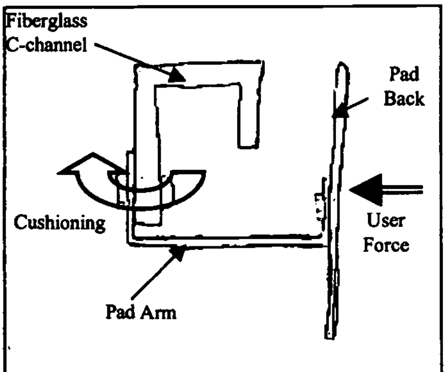


Figure 3
C-channel Cushioning Concept

A single rod/pad/connector assembly, intended to support the lumbar region of the back, was built to evaluate the functionality. Through customer evaluation, especially with our primary customer, Mike, we found that while the concept was novel and met the functional requirements, several issues needed to be addressed. The system functioned as designed, but the fiberglass was too brittle to withstand the high dynamic forces, causing hairline cracks in the channel. We had failed to recognize the size of the impact load imposed by our main customer as he moved into the chair. Outside of this, we found that there was too much deflection due to dynamic cushioning, allowing the rod to disconnect during normal usage, which is unacceptable. The following changes were made for the beta prototype and are shown in Figure 4:

- Rod material was changed to aluminum angle.
- Static force analysis increased to 300 lbs.
- Modular connectors were redesigned to be more secure.
- Hinge added to the pad back.
- Created a foam pad and cover, to be removed as a unit.

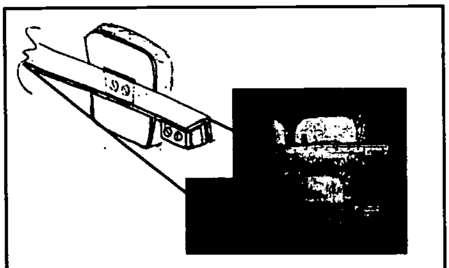

Figure 4 - Final rod/pad design

In order to choose the correct size of aluminum angle iron, a series of FEAs were performed. In order to keep the weight down and keep the bending to a minimum, angle aluminum was chosen.

The FEA showed that a minimum of 3/16" thick, 1"x1" was required in order to support a 300 lb. person with a factor of safety of three.

The beta design was tested on a Breezy 510 collapsible wheel chair, which has a width of 18" and maximum back height of 15". Because of the limited area, two rods were used with three pad backs, also made of aluminum. This configuration is adjustable to different chairs with the choice of additional rods or head support. The pads are attached to the rod with small hinges, allowing the pad to tilt backwards under force. The connectors have a v-notch in order to fit side-posts of up to 1" diameter. A slot/pin configuration is used to securely tighten it to the side-post. Between all metal-to-metal interfaces, a 1/16" rubber pad is placed to reduce slippage and wear on the parts.

The padding is cut ½" longer than the pad back on all sides. This adds cushioning to the edges, all of which have been rounded. Vinyl with a flannel back encases the foam and is attached to the pad pack using Velcro, so it can be removed for washing. This pad design allows the user to customize the feel by adding different types of foam, as well as adjusting the position and orientation of the pads.

**DESIGN EVALUATION**

The beta design provides a significant amount of customization in the x, y, and z directions, as shown in Figure 2. Pad can be placed in several locations along each rod, providing for asymmetric adjustment in the x-direction. A rod can be placed in the center, along the top, or along the bottom of the pad, or the rod itself can also be placed at various points on the side-posts, providing multiple y-direction adjustment. z-direction adjustment is provided by the use of spacers, which can be placed either in front or in back of the rod.

The hinges reduce the potential for having the pad back dig into the user when they are wheeling along or moving into the wheelchair and add to the comfort level. The overall weight of the system is 4 lbs, which did not meet our original goal of 2 lbs; however, this weight still competes with existing back support systems on the market that don't offer as much customizability or ease of fabrication.

**CONCLUSIONS**

The final product meets all the needs of the market, especially our focus customer. It fits on a collapsible wheelchair, has pad adjustments in 3 axes, and has a single design cost less than $200. The use of the hinge reduces the impact of the pad back edges and provides dynamic cushioning, making for a more comfortable chair. This type of "floating" backrest is not currently on the market and could have significant impact on wheelchair backrest design. Some variations on the design would be to use a telescoping rod so that it could fit various chair widths. Hinges with tension could be used to give a softer feel to the dynamic cushioning. The method of damping in the alpha prototype could also be explored further. The prototype backrest was turned over to the Services for Students with Disabilities department at the University of Texas, to be used by students who are in need.

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# A NEW UNIVERSAL CANOE SEATING SYSTEM: EFFECTS ON USER BALANCE AND PADDLING STRENGTH

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## ABSTRACT

This study evaluated the effects of a prototype universal canoe seating system on tipping tolerance and paddling strength within a small group of individuals with and without disabilities. A seat base module attached to the canoe bench provided padding and pelvic support. Additional supports were available to provide trunk and leg stability, to further aid independent sitting. The angle of lateral tip and force generated by a paddle were measured for 22 subjects: 16 with disabilities that limit independent sitting and 6 non-disabled. Preliminary results suggest that this universal canoe seating system greatly enhances sitting balance and paddling strength for people of all abilities.

## BACKGROUND

Many canoeists with disabilities lack the balance and leg strength required to independently sit on a canoe bench seat. Members of this population usually sit on the bottom of the canoe, stabilizing themselves against the bench and sides of the canoe, thereby passively participating. Currently available canoe seats do not effectively stabilize the pelvis or provide lower back or leg support for users with limited sitting balance.

The universal canoe seating system (Figure 1) allows people with disabilities that prevent or limit independent sitting to maintain balance while sitting on the canoe bench (1). The seat base module clamps to a standard canoe bench seat and adjusts to provide lower back and pelvic support for various users. Supports for the upper back, trunk and knees can be attached for users who need additional positioning and stabilization. Pelvic stability is critical in maintaining good posture, which enhances upper body movement. Sitting on the bench, centered over the keel in a stable manner, allows the canoeist to actively participate in paddling the canoe and provides the canoeist with a better view.

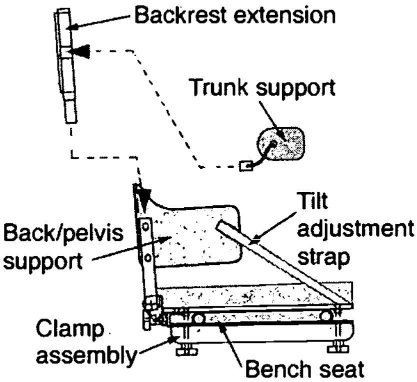


**Figure 1. Universal Canoe Seat**

## METHODS

Preliminary subject evaluations were conducted to compare the user's balance and paddling strength while using a standard bench-style seat with no modifications to that of the universal canoe seating system. The universal canoe seating system was equipped with upper back and knee supports as requested by each individual.

Twenty-two subjects participated in the study: 8 with a spinal cord injury (SCI), 8 with other disabilities including SCI with polio (SCI/P), cerebral palsy (CP), brain injury (BI), shoulder muscle weakness (MW), primary lateral sclerosis (PLS), and degenerative joint disease (DJD), and 6 had no disability (ND). The subjects, 12 males and 10 females, ranged from 8 to 72 years of age, 52 to 78 inches in height and 68 to 190 pounds. The subjects' canoeing and kayaking experience varied from beginning to advanced.

Lateral Canoe Tip

A canoe mounted on a test fixture was used on land to tip the canoe laterally in a controlled and safe manner. Each subject was instructed to maintain balance by extending their arms horizontally while the canoe was rolled to each side as far as possible. A digital level across the sides of the canoe measured the maximum angulation achieved by each subject before loss of balance.

Paddling Strength

Each subject held a paddle and simulated a paddle stroke, applying maximum force for 2 seconds while maintaining balance. The maximum force achieved by each subject was measured using a force transducer that was mounted between the paddle blade and the front of the canoe.

Data Analysis

Each subject performed both tests two times on the right and left sides while sitting on the standard bench-style seat and then while using the universal canoe seating system. Lateral canoe tip values were calculated for each subject by averaging the maximum values obtained on the right and left sides. For paddling strength analysis it was presumed that the subjects were more consistent and would generally use their stronger side; therefore the maximum value obtained from all trials was used. For each subject, the percent change was calculated by subtracting the value obtained on the standard bench-style seat from the value obtained while using the universal seating system and then dividing by the value obtained on the standard bench-style seat.

## RESULTS

Lateral Canoe Tip

All 16 subjects with disabilities achieved greater lateral tip using the universal seat (an average of 91% ranging from 8-204%) (Figure 2). The five ND subjects who performed the tip test also achieved greater lateral tip using the universal seat (an average 167% ranging from 52-302%) (Figure 2). These results suggest that the universal seating system allows canoeists to achieve a greater degree of lateral tip using the universal seat than when using the bench seat in the canoe.

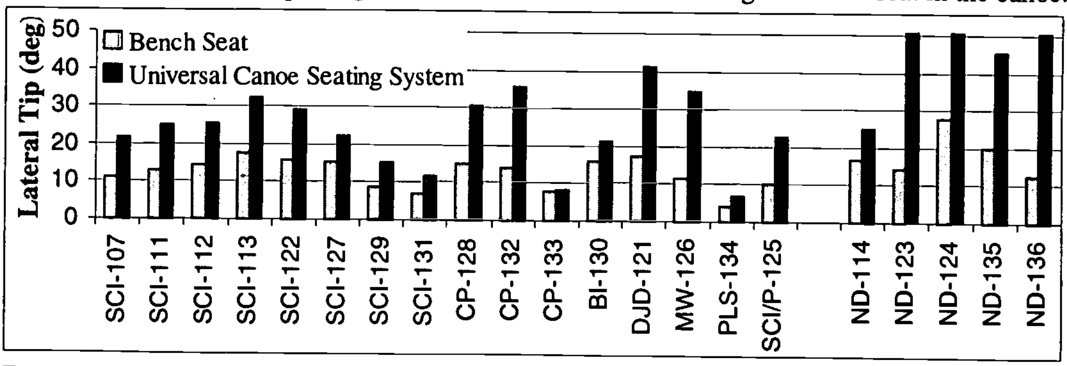


**Figure 2. Results of Lateral Canoe Tip Test**

Paddling Strength

All 16 subjects with disabilities produced more force using the universal seat (an average of 60% ranging from 12-186%) (Figure 3). Five of the six ND subjects produced greater paddling force using the universal seat (an average of 67% ranging from 6-178%) while no change was exhibited in one subject (Figure 3). These results suggest that the universal seating system allows canoeists to generate more force using the universal seat than when using the bench seat in the canoe.

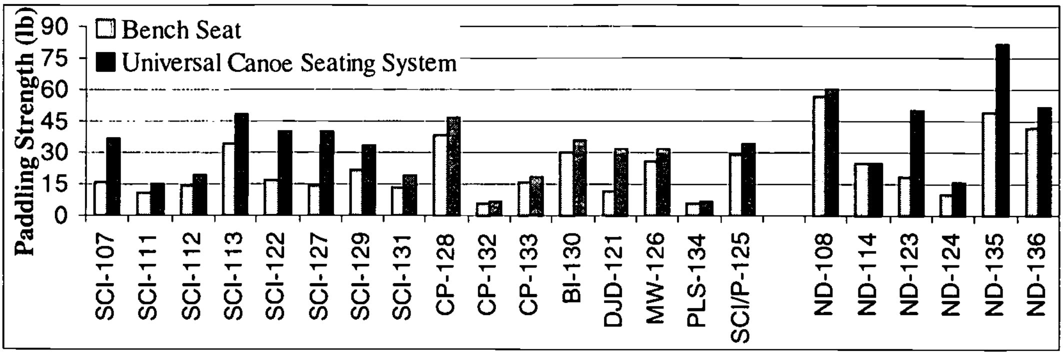


**Figure 3. Results of Paddling Strength Test**

## DISCUSSION

The universal canoe seating system allowed all 21 subjects to achieve a greater degree of lateral tip than they could while using the standard bench seat. This is attributed to the increase in balance from the support and stability that the universal seating system provides. Furthermore, 21 of the 22 (95%) subjects were able to generate more paddling force than they could while using the standard bench seat. This increase in force generation was attributed to the stability provided by the universal seating system, which allowed the subject greater leverage. In summary, these preliminary results suggest that the universal canoe seating system will allow people with limited sitting balance a greater ability to actively participate in canoeing. The universal seating system also benefits the non-disabled population by providing pelvic support and increased stability. Water testing is also being conducted to investigate how the universal canoe seating system affects the paddler's performance during actual canoeing and how the simulation testing on land predicts paddling performance on water. This research is currently in progress; additional subjects representing a broader range of disabilities will be included in the final results.

## ACKNOWLEDGEMENTS
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# STORABLE AUTOMATED DESK MOUNTED ON WHEELCHAIR

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## ABSTRACT

This project has been designed for a teenage male confined to a wheelchair with Muscular Dystrophy. Currently, a lap tray is placed in front of him at school to work on. His desire for independence has inspired us to design a desk he can automatically move with a switch. The desk, mounted on the rear of the wheelchair, stores behind the chair and rotates up and over his head to a usable position. A linear actuator extends the desk when passing over the client's head and retracts it to a usable position, as well as a storage position. A number of sensors are placed on this device to stop motion in hazardous situations. An electronic brake prevents the desk from moving when the rotational motors are not active.

## BACKGROUND

The client is a teenage boy with Duchenne Muscular Dystrophy. This x-linked recessive genetic disorder progressively deteriorates muscle mass over time. The gene mutation disallows the production of dystrophin protein [1]. The first symptoms typically begin at ages 2 to 5, and the patients are confined to a wheelchair on average by age 12 [2]. The disease continues to decrease voluntary muscle mass to a point of near paralysis [3].

The client is at a point where forceful movements, especially against gravity, are difficult. His arms are confined to a small workspace in front of him, and he uses fine finger movements. His daily activity depends upon a motorized wheelchair, the Ranger X Storm Series® (Invacare Corporation, Elyria, Ohio). This wheelchair has a joystick on the right armrest to drive the chair.

As a junior in high school, the client currently uses a small lap tray for reading and writing. To be more independent, the client desires a desk that he can place in front of him without anyone's assistance. No commercially available devices fit this need.

## PROBLEM STATEMENT

The goal of this project is to design and construct a safe, switch-operated automatic desk for the client. It must have a workable surface area and not interfere with the normal operation of his chair. It must easily be stored and as well as easily moved into position for usage.

## DESIGN AND DEVELOPMENT

The wheelchair cannot be made any wider, or it will be difficult for the client to pass through doorways. It was therefore concluded that the desk needed to be stored behind the chair and rotated over the client's head into the working position.

To function in this manner, the desk extends to safely pass over the client's head. It also retracts so that he may work on it, and so that it can be stored without hitting the ground.

The desktop is constructed from clear ¼" polycarbonate, with a steel reinforced under-frame. This assembly attaches to linear bearings (telescoping rails), similar to those used on sliding drawers, for mobility (see Figure 1). A 24VDC linear actuator (Dayton® 2506) controls the extension and retraction of the desk.

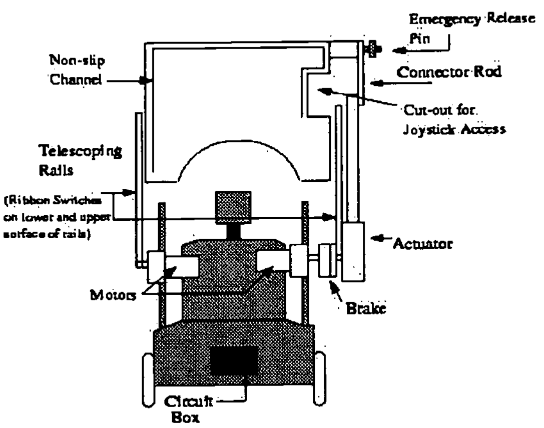


Figure 1: System Layout

In the initial design, the desk and actuator were to be rotated from the storage position to the armrests by a single 12VDC gearmotor (Dayton® 1L474). This motor, located on the left-hand side of the unit, is capable of producing 500 lb-in of torque. The maximum speed is 6 rotations per minute. A pulse-width-modulated speed controller is integrated into the electronics and is used to adjust the motor to the desired speed.

Upon completion of all the mounting brackets and the test frame, we found that 500 lb-in was insufficient torque to rotate the desk. In performing a thorough torque test, by replacing the motor with a torque wrench, it was discovered that at least 600 in-lb of torque was required to rotate the desk. The Boston Gear Company generously donated at 2:1 90° bevel gear reducer. This would double the torque of the existing motor while halving the rotational speed. However, the bevel gear reducer was far too large to be incorporated into the design, since the mounting space behind the client's wheelchair is extremely limited. The idea of mounting the unit under the chair and using a flexible shaft was also deemed unfeasible for spatial purposes.

It was finally determined that a second motor would be needed, which would be mounted on the right side of the wheelchair. This would provide a combined torque of 1,000 in-lbs, sufficient to rotate the desk.

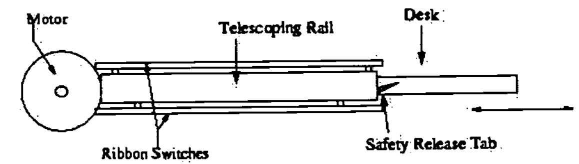


Figure 2: Left side motor (side view)

Numerous safety features have been incorporated into the design. An emergency release pin, which uses a spring-loaded bearing mechanism, is located at the connection between the linear actuator and desk (see Figure 1). Safety release tabs are also located on the outside of the sliding rails (see Figure 2). When the pin is released, and safety tabs are depressed, the desk glides forward and off. In addition, a power-off electronic brake (Warner Electric® ERS-57) holds the desk from rotating whenever the motors are not powered. A specially designed mounting plate was machined out of ¼" steel and welded together so that the brake, motor, and actuator could all mount together to the right side of the wheelchair frame. On the left side, a ¼' steel mounting bracket was fabricated for the single motor. All fasteners are Grade 5 bolts and nylon insert locknuts, to prevent loosening due to vibration.

A number of sensors and electronic logic circuits ensure safe operation of the desk. Along the linear actuator, upper and lower limit reed switches determine when full extension and full retraction of the desk have been reached, respectively. These switches are closed when contacted by a magnet mounted to the actuator shaft. Five mercury tilt switches are orientated at various positions on the actuator side of the desk. The combinations of signals from these switches at any given time are processed by the circuit board and dictate the position of the desk. The logic is designed to prevent the desk from ever touching the client or his wheelchair. For example, if the desk is rotated back from the lap position, the actuator must be fully extended or the desk cannot move beyond a certain limit. This prevents the client from being struck by the desk. Additionally, as shown in Figure 2, ribbon switches placed along the upper and lower edges of the desk will stop all motion if the desk comes into contact with an object.

The device is controlled with two remote single pole-double throw switches, one for the motor forward and back, and the other for actuator extend and retract. The electronics are housed in a resilient plastic enclosure. The circuitry also contains a power conservation relay to minimize current draw when not in use, which significantly increases the time required between charging of the batteries.

## EVALUATION

Evaluation of the completed design on the client's wheelchair indicated that all functions of the automatic desk work as intended. Nevertheless, further work is necessary to improve the overall appearance, to provide further clearance in two positions, and to build a printed circuit board for the electronics.

## DISCUSSION AND CONCLUSIONS

With the use of two switches, the client can move a desk into a workable position, and retract it to a storage position. Operation of the device is done entirely independently. The desk is stored behind the wheelchair where there is minimal interference with the normal functioning of the chair. The design incorporates numerous safety features, which work together effectively to control the rotation, extension, and retraction of the desk. The nature of this project is such that the client will rely on it heavily, using it continuously throughout the day. For this reason, future development, perhaps involving an industrial team, is required to address remaining issues such as product reliability and comprehensive safety testing.

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## Acknowledgments

The engineers on this project would like the thank Joe Owen and John Goodfellow for their machining of parts. We would also like to thank Paul Salvucci, from Boston Gear, for donating the bevel gear reducer. In addition, we extend our gratitude to our instructor Dr. Laurence Bohs for his invaluable assistance and to Brian Pullin and Mark Palmeri for their work on the initial stages of this project.

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# MOTORIZED SWING FOR CHILD UP TO FIFTY POUNDS

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## ABSTRACT

Our client is a four-year-old boy with Cerebral Palsy. He has limited vision and mobility and is adult dependent. He enjoys motion, especially swinging. The goal of this project was to provide our client with a device he can control himself and that will give him motion. We designed and constructed a motorized swing that our client can control with a switch. This swing is sturdy for a child up to fifty pounds in weight, semi-portable, and it provides appropriate support for our client as he swings. Our client seemed to enjoy the swinging motion, indicating that this project was a success.

## BACKGROUND

Our client has Cerebral Palsy. This is a medical condition caused by damage to the brain that typically results in a person having reduced control over movement and posture. This is the case with our client. He also has limited visual ability that is common among those with Cerebral Palsy (1). He is reliant upon adults and can do very few activities independently. Our client can press a switch, and he understands cause and effect relationships. A device that he can control himself would be therapeutic.

Our client enjoys swinging. Both his mother and his therapist expressed that he loves the motion of swinging more than any other motion. Since he understands cause and effect relationships and enjoys swinging his therapist suggested a motorized swing would give him some independence in an activity he enjoys.

Motorized swings are sold commercially, but they only exist for infants and usually hold a maximum of only twenty-five pounds. Our client is too large to use these swings. A customized swing to accommodate his size is necessary.

## PROBLEM STATEMENT

The goal of this project was to build a motorized swing that our client can control independently. The swing needed to be semi-portable so as to move it from inside the home to outside; allow for some varying range of motion; and provide the child with proper constraints and supports. Most importantly, the swing had to be safe for our client to operate for extended lengths of time. It needs to give him independence and enjoyment.

## DESIGN AND DEVELOPMENT

After identifying the need of the client an extensive search was done of existing patients and also of designs from National Science Foundation Engineering Design Projects to Aid Persons with Disabilities. Tiwanna N. Bazemore and Addie E. Dillon developed the "Switch Activated Swing for Children up to 50 Pounds" (2) at North Carolina State University. It provided the basic design for converting the rotational motion of a motor into a swinging motion.

The basic swing drive mechanism is drawn in Figure 1. A drive plate (#1) is attached to the motor (#3). This has a pin that inserts into the oval cutout on the Swing Drive Mechanism (SDM) (#2). As the motor spins the drive plate, the pin causes the SDM to move in an oscillatory manner about a crossbar (#4). The SDM is attached by hex nuts (#5) to a stiff U shaped structure (#6). The ropes are attached to the bottom of this. Originally there was concern that the stiff connection between the SDM and the U structure would cause a dual pendulum effect. But, once the device was tried in lab it was discovered that the flexibility of ropes made up for any discrepancy between the natural frequency of the swing and the speed of the drive plate.

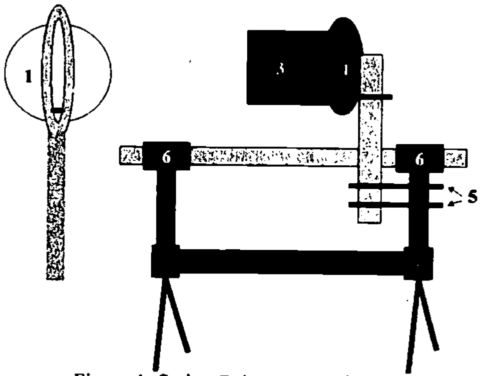

Figure 1: Swing Drive Mechanism

The swing is pictured in Figure 2 and is meant for both indoor and outdoor use, so a lightweight frame was ordered to increase portability. The frame was stabilized by filling the lower legs with sand to add the necessary weight to prevent the swing from moving around. This replaced the need to stake the frame into the ground. The motor mechanism is mounted on the crossbar at the top of the frame. Although this places the motor directly above the head of the user, this is the only structurally sound place for the motor to go.

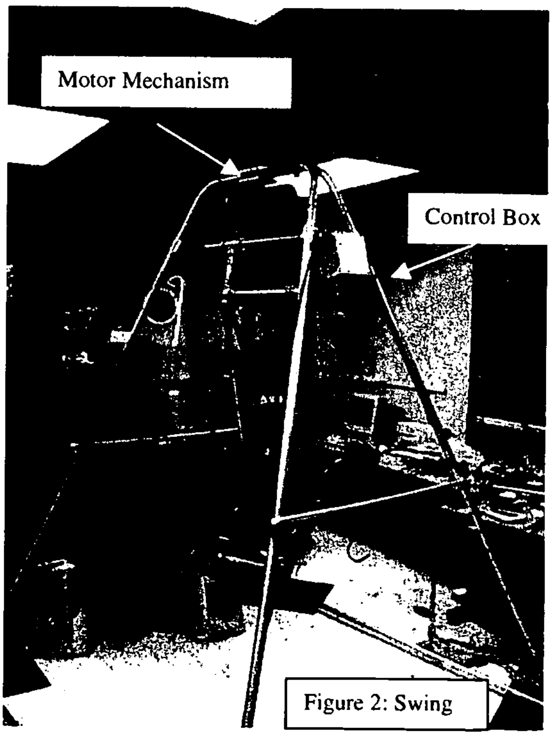

Figure 2: Swing

The motor is a 12 V DC motor powered by a computer power supply. The control circuitry is mounted on the side of the frame near the top to make sure that only adults can reach the control device. As a safety precaution a 10 A fuse has been included in the circuit as well as a ground fault circuit interrupter. Since the frame is metal, the entire swing has been grounded.

## EVALUATION

At varying motor speed, the swing seat moves differently. In order to obtain the smoothest movement of the seat, the revolutions per minute and the natural frequency of the seat swinging movement (1/seconds) should match closely. The natural frequency of oscillation of a pendulum is determined using the following equation:

$$Frequency = \frac{\sqrt{g}}{2\pi\sqrt{L}}$$

where g is the acceleration due to gravity (32.2ft/s) and L is the length of the pendulum. In this case, the length of the pendulum is the distance from the crossbar to the bottom of the seat. Once the seat was positioned correctly the motor speed was adjusted to match the resulting natural frequency of the pendulum.

Once the swing oscillated in a smooth manner, adding weight to the swing seat tested the movement. Weights were added in increments of five pounds until the weight reached a maximum of fifty pounds. As the weight increased, the seat tended to oscillate even more smoothly and with constant speed. This is likely due to a lessening of the affects of air resistance in the system with larger weights. More weight results in more inertia and so the swinging motion is easier to maintain. With a maximum of fifty pounds of weight added, the frame was stable for extended lengths of time, and the motion of the seat was constant.

By altering the placement of the bearing-drive plate connection in the system, the range of motion of the seat was varied. With both the smallest range of motion setting and the middle setting, the swing movement was smooth and constant during tests with our client. The largest motion setting was tested only with weights because space limitations in lab made it impossible to test with the client.

## DISCUSSION AND CONCLUSIONS

This device provides the client with an independent activity that he enjoys greatly. Not only is he enjoying himself, he is also learning about cause and effect. The greatest limitation on this swing is that the frame can only hold 50 pounds and it not very portable. The motor mechanism can drive more then 50 pounds, so if additional work is done to build a stronger frame, this device could serve the client into adulthood. This project was a success by providing our client with a safe, independent, and enjoyable activity.

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## ACKNOWLEDGEMENTS

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MOTORIZED SWING FROM SUSPENDED RINGS

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ABSTRACT

The goal of this project was to design and construct a device to swing a child from rest for extended periods of time. The swing is suspended from two rings, which support the swing's driving mechanism, as well as the user. An offset crank converts rotational motion to oscillatory action. The swing has been successfully tested using appropriate weights, and human users. The final product is expected to provide hours of enjoyment for the client.

## BACKGROUND

The client is an eight-year old girl with cerebral palsy, spastic quadriplegia, blindness and half-hearing loss. Due to her limitations, swinging is one of the few stimuli she can enjoy. She presently uses a swing that must be pushed manually by one of her parents. Her family desires a motorized swing, because she often desires to swing for hours at a time. She is now 56 pounds, 42 inches tall, and has long outgrown her commercial motorized infant swing.

## PROBLEM STATEMENT

The goal of the project is to construct a motorized swing the child can enjoy through adulthood. She is developing normally, and therefore the swing should safely support users up to 150 lbs. The swing should be portable and easy to set up, to be used on the family's porch and at the client's school.

## DESIGN AND DEVELOPMENT

The swing is designed to suspend from two rings for compatibility with both the client's porch and school. This design eliminates the need for a frame and increases the swing's portability.

The swing's driving mechanism consists of a variable speed motor with an offset crank, and a drive channel attached to a drive shaft. The offset crank moves in the channel and oscillates the drive shaft, which is mounted with pillow block bearings to the swing suspension system (shown in Figure 1). The swing drive mechanism is based on the design of a commercial motorized infant swing (1). The driving mechanism is mounted rigidly to the swing suspension system, which uses eye-bolts screwed into overhead attachment points such as ceiling beams. A solid square steel rod slides through both eye-bolts, and brackets clamp onto the rings to prevent the rod from rotating. The swing driving and suspension systems are then mounted to this stationary square rod (shown in Figure 1). The suspension system is comprised of two rods, which act as lever arms to push the swing. These rods are connected together, and attached to the solid square rod by three pillow block bearings.

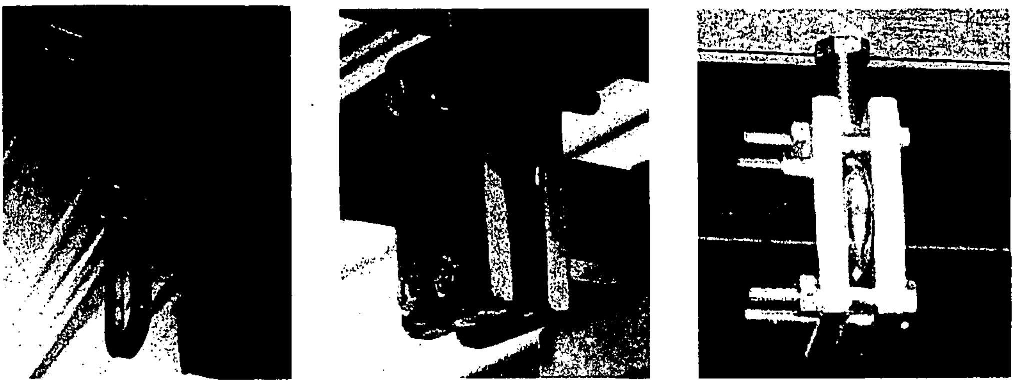

**Figure 1 – Motor , Offset Crank and Drive Channel (Left), Rod Mounting Brackets (Center & Right)**

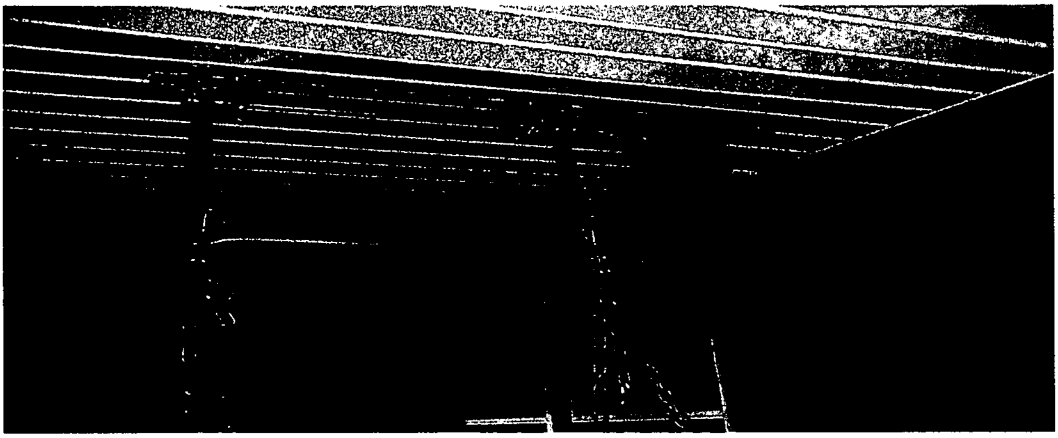

**Figure 2 - Entire Swing**

Figure 2 shows the overall swing design. Three pillow block bearings suspend from the square rod and permit smooth rotation of swing's drive shaft. One-foot rigid swing arms attached to this oscillating rod provide a sufficient push to start the swing. Adjustable-length chains connect the swing seat (not shown) to the swing arms, allowing the swing to gradually obtain the speed of the driving motor. This design is compatible with any seat that can be attached to two chains, providing customization for a given user. Switching seats involves detaching two carabiners that attach the seat to the chains.

The swing is powered using standard 110V AC power, with a GFCI (ground fault circuit interrupter) attached for electrical safety. A variable speed control converts the AC input to 90V DC for the DC gearmotor, and allows adjustment of the motor speed to match the natural frequency of the swing. Three variable settings in the offset crank allow for the different swing angles, and therefore, swing speeds. As the length of the offset crank is increased, the angle through which the swing oscillates is increased as well. Since the time of one period remains the same, a larger angle results in a faster swing.

As expected, safety of the client played a large role in the design. The attachment to two suspended rings prevents the possibility of tip-over. Using the client's own swing ensures appropriate harnesses will be present to hold her in place. All electrical components are grounded, and the GFCI prevents shock risks.

## EVALUATION

The final swing design was tested using no weight, 25 lbs., 50 lbs., and 170 lbs. For each trial, the swing started properly from rest, and swung to the predicted arc. Human trials were conducted to confirm the weight limit, and to observe the smoothness of the swinging motion. Additionally, a finite element analysis using Pro/MECHANICA was performed on the offset crank, which was considered the most crucial component of the design, to predict its maximum von mises stress and insure it was within the limits of the materials used.

## DISCUSSION AND CONCLUSIONS

While this device was made for a specific individual, the design is universal. It can be used in any location with two suspended eye bolts, used with any seat, and can swing individuals up to 150 pounds. This project will fit the client's needs, allowing her to swing for as long as she desires without needing a parent to swing her.

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## ACKNOWLEDGEMENTS

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# EVALUATION OF MANUAL WHEELCHAIR SKILLS: IS OBJECTIVE TESTING NECESSARY OR WOULD SUBJECTIVE ESTIMATES SUFFICE?

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## ABSTRACT
We tested the hypothesis that subjective estimates of manual wheelchair skills accurately reflect the results of objective testing. Twenty-one wheelchair users (WCUs) and their therapists subjectively estimated the WCUs' abilities, followed by objective testing with the Wheelchair Skills Test (*WST*). Correlation coefficients between the total objective and subjective scores were 0.95 for WCUs and 0.75 for the therapists, but the differences were significant for WCUs ($p = 0.0002$), who overestimated their abilities. Of the percentage concordance values for the 50 individual skills, 28% and 38% (for WCUs and therapists respectively) were not significant. Objective testing is required to obtain an assessment of manual wheelchair skills that is both accurate and comprehensive.

## BACKGROUND
The Wheelchair Skills Test (*WST*) is an objective evaluation of 50 manual wheelchair skills, spanning the spectrum from those as basic as applying the brakes to those as difficult as climbing curbs and performing wheelies (1). The *WST* was designed to meet the need for a comprehensive but practical instrument for the evaluation of manual wheelchair skills. In a pilot study of 24 wheelchair users (1), the *WST* was found to be practical, well tolerated, safe, and to have good measurement properties. However, the sample size was small and a number of remediable problems and unanswered questions about the *WST* were identified.

One such question (and the focus of the present study) is whether objective testing of manual wheelchair skills is necessary. Occupational and physical therapists spend many hours during the rehabilitation process prescribing wheelchairs, adjusting them and helping WCUs learn the wheelchair skills required for activities of daily living. It is reasonable to assume that these clinicians and the WCUs themselves are familiar with skills that have been mastered and those that still pose a challenge. If the therapists or the WCUs could accurately report which skills the WCU is able or unable to perform, then subjective documentation could replace objective *WST* testing. Subjective assessment would require less time, equipment, and space than the objective *WST*. However, studies in other domains have found discrepancies between subjective and objective testing (2,3).

## RESEARCH QUESTION
The purpose of this study was to test the hypothesis that subjective estimates, by WCUs and the therapists working with them, of the ability to perform manual wheelchair skills accurately reflect the results of objective testing.

## METHODS

We studied 21 WCUs (6 with stroke and other acquired brain disorders, 5 with spinal cord and peripheral neurological disorders, 5 with lower-limb amputations and 5 with musculoskeletal disorders) and their therapists (n = 9). Subjects were evaluated in wheelchairs that they had been using for at least 48 hours. The WCUs and therapists predicted whether the WCU would be able to perform each skill. Then, objective *WST* testing (Version 2.3) was carried out.

For each skill, the percentage concordances were calculated between objective testing and both the therapists' and the WCUs' subjective estimates; the statistical significance was determined using an Exact test. We compared the total subjective and objective scores using Spearman correlation coefficients, contrasted them with paired *t* tests and generated scatterplots for qualitative evaluation. We used a repeated-measures multi-factor ANOVA to evaluate the effect on differences between the subjective and objective total scores due to age, gender, diagnostic category and the durations of overall and current wheelchair use. We defined statistical significance as $p < 0.05$ for statistics involving the total scores, but carried out a Bonferroni adjustment for the individual skills ($p < 0.05/50 = 0.001$) to eliminate the effect of multiple comparisons.

## RESULTS

The Spearman correlation coefficients between the total objective and subjective scores were 0.95 for the WCUs and 0.75 for the therapists. The differences between the total objective and subjective scores were statistically significant for the wheelchair users (mean difference 3.1, SD 3.1, $p = 0.0002$), but not for the therapists ($p = 0.74$). These relationships are illustrated in Figure 1.

The percentage concordance values for individual skills ranged from 57.1-100% for the WCUs and 50-100% for the therapist estimates, with 28% and 38% of skills respectively for which there were no significant associations between subjective and objective measures. Examples of such poorly predicted skills were picking an object off the ground, reaching a high object, armrest skills, folding/opening the wheelchair, transfers, incline ascent, negotiating gravel, irregular surfaces and curbs.

**A** **B**

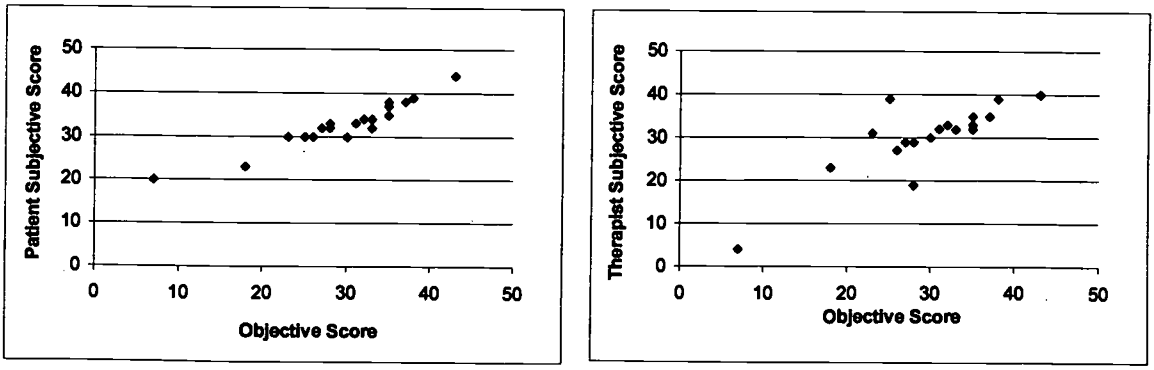


**Figure 1.** Scatter plots of total objective *WST* scores vs the total subjective scores of the wheelchair users (A) and their therapists (B).

There was no significant effect on the differences between the total subjective and objective scores due to age, gender, diagnostic category, duration of overall wheelchair use or duration of current wheelchair use.

## DISCUSSION

Although there was a good correlation between the total subjective and objective scores of WCUs, the WCUs generally overestimated their abilities. For the therapists, the correlation was not as high. The therapists overestimated the WCUs' abilities on some skills and underestimated their abilities on others.

One possible explanation for the discrepancy between subjective estimates and objective testing is that skills that were poorly predicted may not have been part of the rehabilitation program for that WCU. For instance, the WCUs' impairments may have been severe enough that the advanced skills were not practical or appropriate for the WCUs' settings. Alternatively, resource constraints may have led to some WCUs not receiving the wheelchair skills training that they should have. Even if they had received such training, some WCUs may have had impairments of neurological function or mood that limited the accuracy of their estimates. Although it is generally assumed that objective testing is more valid than subjective estimates (2,3), the converse could be true (e.g., if the WCU experienced anxiety during objective testing, if the WCU was transiently tired or unwell, or if the test environment did not closely mirror the WCU's usual setting).

Nevertheless, on the basis of the available evidence, we conclude that objective testing is required to obtain an assessment of manual wheelchair skills that is both accurate and comprehensive.

## ACKNOWLEDGEMENTS

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# WHEELCHAIR-RELATED INJURIES REPORTED TO THE NATIONAL ELECTRONIC INJURY SURVEILLANCE SYSTEM: AN UPDATE

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**ABSTRACT**

We used the data of the National Electronic Injury Surveillance System of the United States Consumer Product Safety Commission 1) to determine the incidence of wheelchair-related injuries that were serious enough to cause the injured person to seek attention at an emergency department and 2) to describe those affected, the injury circumstances and the injuries sustained. The predicted annual incidence rose from 25,829 in 1986 to 85,263 in 1999, with a significant upward trend over time ($R^2$ 95%, $p < 0.001$). Elderly women were most often affected. In 80%, a tip or fall occurred and 17% involved a transfer. Most injuries were minor, but 19.7% were fractures. These findings have important implications for wheelchair design, prescription and training.

## BACKGROUND

There are about 2 million wheelchair users in the United States (1). Through its National Electronic Injury Surveillance System (NEISS), the United States Consumer Product Safety Commission (USCPSC) monitors product-related injuries that are serious enough to cause the affected person to seek attention at one of its representative emergency departments. In a review of the NEISS data from 1986-1990, Ummat and Kirby (2) reported an average national estimate of 36,559 wheelchair-related accidents per year. There was a significant upward trend over time, a trend that we suspected might continue due to the aging of the population (1).

## RESEARCH QUESTION

The objectives of this study were 1) to determine the incidence of wheelchair-related injuries and 2) to describe the people who were affected, the injury circumstances and the injuries sustained.

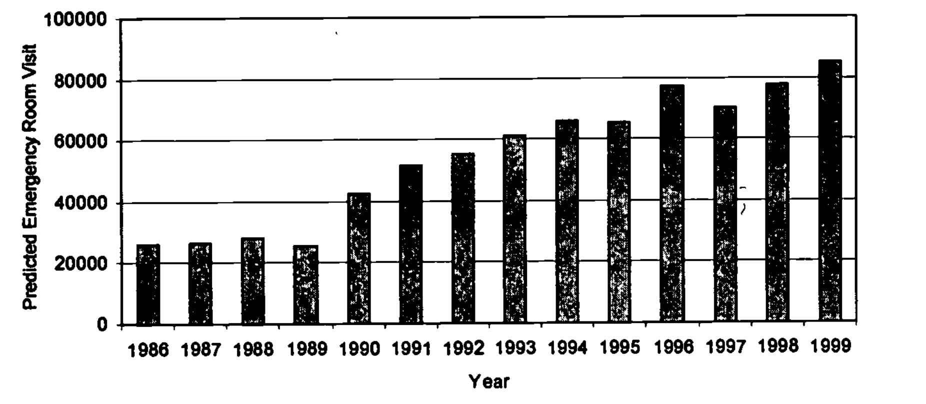
## METHODS

We evaluated in detail the NEISS data from the most recent five years for which complete data were available (1994-1998), 7956 incidents in all. We coded the data for the age and gender of the affected person, whether the affected person was a wheelchair user, the circumstances of the accident, the nature of the resulting injuries, the body parts involved and the disposition of the patient. The raw data were used except when reporting the calculated total annual estimates of accidents. For that, a weighted score was provided by the USCPSC for each case to enable extrapolation to the entire United States and we used the estimates from 1986-1999.

## RESULTS

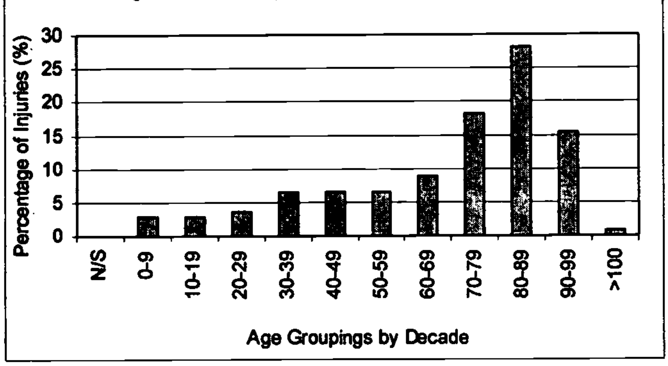
Predicted national incidence. The average annual predicted national incidence rose from 25,829 in 1986 to 85,263 in 1999 (Figure 1), with a significant upward trend over time ($R^2$ 95%, $p < 0.001$).

Figure 1. Predicted Emergency Room Visits by Year




Age and Gender. The percentage of the injuries by the ages of the subjects (in decades) rose substantially to the age of 89, then diminished thereafter (Figure 2). Females were affected in 64.4% of cases.

Figure 2. Percentage of Injuries versus Age Groupings




Injury circumstances. Of the accidents, 38.6% occurred on public property, 33.0% occurred at home and 2.5% on a street or highway. In 80.4% of cases, a tip or fall occurred; 17.1% involved a transfer; in 8.8%, a body part was pinched, caught or hit by the wheelchair; 3.1% involved a collision (e.g., with a motor vehicle, wall, object, pothole, door or another wheelchair) and 7.8 % involved an environmental factor (e.g., van, curb, incline, ramp). In at least 8.4% if cases, the affected person was a non-wheelchair user.

Injury sustained. Of the injuries sustained (Figure 3), lacerations were the most frequent (29.8%), contusions and abrasions next (28.1%), fractures 3rd (19.7%) and strains/sprains 4th (9.3%).

Body regions. Of the body regions affected (Figure 4), the head and neck region was the most frequent (39.7%), followed by the trunk (22.4%), the legs (21.9%) and the arms (13.4%).

Figure 3. Percentage of Total Injuries vs Diagnosis

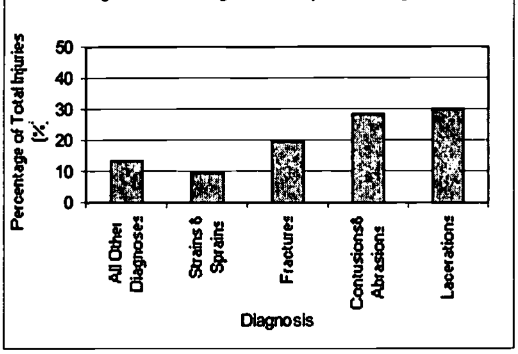
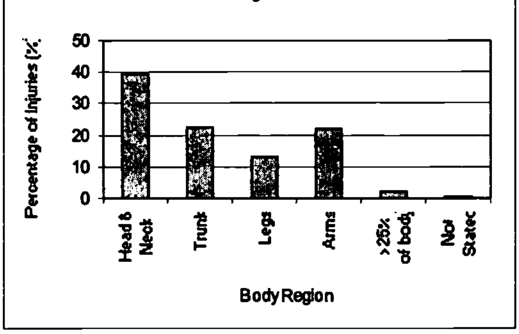



Figure 4. Percentages of Injuries to Specific Body Regions




Disposition. Most patients (87.5%) were treated and released, but 12.3% were treated and admitted hospital. Four patients (0.05%) were dead on admission or died in the emergency department.

## DISCUSSION

The predicted annual incidence rose substantially over the 14 years between 1986 and 1999. Except for the incidence, the pattern of findings for the most recent five-year period for which complete data were available (1994-1998) was consistent with our earlier report on the NEISS data of 1986-1990 (2). Earlier reports on the death-certificate databases of the USCPSC (3) and the US Food and Drug Administration (4) should also be updated. These epidemiological findings have important implications for wheelchair design, prescription and training.

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# DEVELOPMENT OF A PROTOTYPE RETRACTABLE WHEELCHAIR FOOT TRAY

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## ABSTRACT

A young woman with Dystonia is confined to a wheelchair and uses her feet to perform daily tasks of living. To accommodate such activities, she requires a work surface at her foot level. The goal of this project was to design such a work surface that is retractable and detachable from the user's powered wheelchair and can be operated independently by the user. The team designed and built a portable foot tray system that attaches to the undercarriage of the woman's electric wheelchair. The prototype system was fastened to the wheelchair and evaluated for 7 weeks. The young woman used the device independently at home, school, and in physical and occupational therapy sessions.

## BACKGROUND

The device was designed for an active sixteen-year-old girl enrolled in public high school. She previously used a manual wheelchair and pulled herself around by "walking" the wheelchair with her legs. With the floor as a work surface, the woman became very adept at using her feet to carry out many daily tasks. Recently she was refitted with a powered wheelchair. Although the powered wheelchair has greatly increased her mobility, it is configured at a height such that her feet are positioned several inches above the floor, eliminating the option of using the floor as a work surface. She requested that her wheelchair be outfitted with a retractable, removable foot tray system at her foot level that she can operate independently and is available to her anywhere.

## STATEMENT OF THE PROBLEM

The young woman requires a work surface at her foot level. The problem was to design and fabricate a work surface she can operate independently, is retractable, and can be detached from and reattached to her powered wheelchair.

## RATIONALE

Development of a portable, retractable wheelchair foot tray system will supply a work surface for the young woman to carry out daily tasks wherever she goes. Moreover, introducing a system that must be manipulated independently will increase the user's motor skills and self-independence.

## DESIGN

The following major design goals were established. The user must be able to independently deploy the tray when her leg rests are swung away and then tuck it away when not needed. The surface area of the tray must be strong enough to support various objects and provide the user with enough room to carry out desired tasks. The device must easily detach from and reattach to the wheelchair using no tools and without irreversible modification of the wheelchair. Finally, the device must not interfere with the functionality of the wheelchair or any of its components.

## DEVELOPMENT

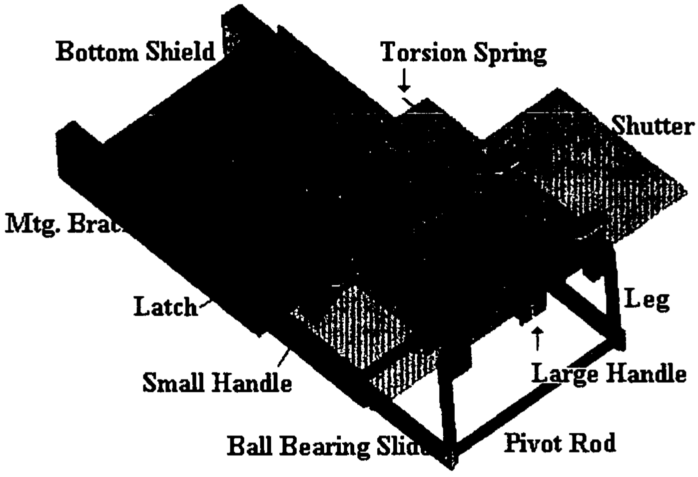


Figure 1. Computer Model of the Foot Tray

The foot tray was modeled in Pro Engineer (Figure 1), and a physical prototype was fabricated. The foot tray consists of a flat Lexan surface attached to four pivoting legs that are attached to ball bearing slides. The configuration creates a parallelogram linkage that translates from underneath the wheelchair and rotates up to the user's foot level. Torsion springs are mounted between the tray legs and surface. Analysis was performed to determine the torque required to rotate the system to various positions from 0 degrees (stowed position) to 90 degrees (deployed position). Torsion springs were selected that would assist in deploying the system (Figure 2).

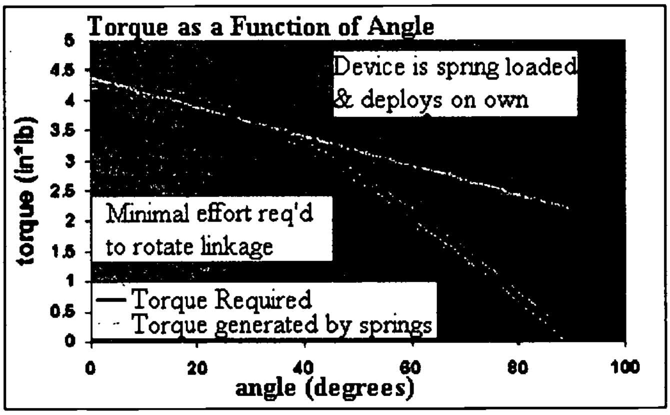


Figure2: Spring Design

The tray features folding shutters that allow a large, flat surface to be stored in a compact area. When opened, the shutters increase the work surface area by 71%. The entire system is stored underneath the wheelchair and held in place by custom mounting brackets that feature quick release spring pins for easy removal of the unit. Four inputs are required to operate this device. The user grips a large handle, with her foot, to pull the tray forward from underneath the wheelchair. Next she pulls a small handle upward to activate the linkage, which brings the tray up to foot level. At this point the latch will automatically engage to lock the tray in its upright position. Finally, she opens the shutters to increase the tray surface area. The foot tray is a custom device designed to work specifically with the user's Invacare ®Ranger X™ Storm Series® wheelchair.

## EVALUATION

Laboratory tests were carried out on all of the steps of deployment of the tray system. A force gage was used to measure the force required to perform each step. The first test was to measure the force required to "unlock" the tray and slide the system horizontally from underneath the battery box. This test was carried out at three different angles of force application – 0, 45 and 60 degrees. The average pulling force required was 9, 10 and 13 lbs. respectively. The next test was to measure the force required to activate the linkage. The average force required to rotate the linkage to the height that would allow the springs to take over was 3.44 lbs. The final test was to measure the force required to open the shutter tops. This test was carried out for two pulling positions 0 and 45 degrees. The average forces required were 3.4 and 2.7 lbs. respectively. All inputs required of the user were well within the limits of her ability.

Field testing of the tray system consisted of a 7-week period of full time use at home and school. The woman could deploy and stow the tray independently and efficiently, requiring a mere 15 seconds to deploy the tray and 10 seconds to stow it. The tray was attached to the wheelchair in the morning at school and removed at the end of the day. The tray surface was large and strong enough to support her schoolbooks, homework, schoolwork, computer keyboard and trackball. The woman's teacher felt that the attachment and removal of the tray was rather difficult for her to accomplish in a timely manner. During the evaluation period the user found that non-ADA ramps and sidewalks consistently hindered mobility. The tray system also bumped the wheelchair lift in the woman's van. This could be compensated for by having the woman back up ramps, but this proved to be difficult due to her medical condition.

## DISCUSSION

A prototype retractable wheelchair foot tray system has been designed, fabricated and tested in the laboratory and with the intended user. Laboratory force tests were carried out to measure the ease of use of the system. Field tests were carried out for a period of 7 weeks. The user could physically deploy and stow the tray independently and efficiently. The ball bearing slides and spring-loaded linkage made the system extremely easy to operate. The steps for deployment were easy for the user to understand and reproduce. The surface area supplied by the system was large enough to hold the required items needed for her daily tasks. Installing the tray beneath the undercarriage, while not optimal, provided the space necessary to store the large work surface. The storage location decreases the ground clearance, which limits the user to travel over smooth surfaces. Also, the user's aids reported that removing the unit from the chair was cumbersome. Nonetheless, the tray served its stated purpose and has proven to increase the user's self-reliance and functional independence.

## ACKNOWLEDGEMENTS

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# STRESS RELAXATION PROPERTIES OF BUTTOCK SOFT TISSUES: IN VIVO INDENTATION TEST

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## ABSTRACT

The buttock soft tissues of six able-bodied subjects were investigated using the Computer Automated Seating System (CASS). In vivo indentation tests were performed and the force-deformation data was fit to the quasi-linear viscoelastic (QLV) model. QLV parameter a, corresponding to the stress relaxation, ranged from 0.067 to 0.328 and the time constant, t, ranged from 44.2 to 164.21. Intraclass correlation coefficient, ICC (3, 1), values for a and t were larger than 0.72. The results demonstrated the reliability and repeatability of our in vivo buttock soft tissue assessment process and suggested that QLV parameters from the six subjects are correlated.

## BACKGROUND

Prevention of pressure ulcers by identifying individuals with high risk was singled out as a top priority by the Agency for Health Care Policy and Research (AHCPR, 1992). Results from past research led us to consider the use of biomechanical properties of soft tissue in the risk assessment process. Biomechanical properties are indicative of the tissue's ability to resist damage caused by external pressure. Other investigators use of ultrasound indentation systems to assess the biomechanical properties of lower limb soft tissues [1] led us to the technique described here for buttock soft tissues.

## RESEARCH QUESTIONS

This research was designed to assess the reliability and repeatability of the in vivo test protocol and determine the suitability of the QLV model for characterizing the buttock tissue's response. Specifically, what are the ranges of QLV parameters, a, and time constant, t, of healthy buttock tissues in the seated posture? In addition, is there correlation between the QLV parameters from the six subjects in this able-bodied subject group?

## METHOD

Six male subjects without any neuromuscular disease were enrolled in the study. A percent body fat measurement was recorded for each subject using a Fat Gun Skinfold Caliper (Creative Health Products, Inc.). The thickness of the fold of skin with its underlying layer of fat at four prescribed locations (biceps, triceps, subscapular, and suprailiac) on the body were measured. A B-mode ultrasound exam was performed to measure the thickness of soft tissue layers (skin, fat, and muscle) at the test site (4-cm in front of ıe ischial tuberosity).

Fig.1 Experimental set up

An indentation test was performed using the CASS (Fig.1) [2]. Each subject was seated on the CASS with the test site positioned above one of the sensors equipped with force and ultrasound transducers. An indentation test consisting of indentation, hold, and recovery phases was performed. Automated echo tracking techniques were used to track tissue layer thickness. Tissues thickness, force and tilt angle were recorded throughout the loading cycle.

Fung's QLV theory [3] describes the stress relaxation,

$$P[u(t); t]=G(t)*P^e(u) \qquad G(0)=1 \qquad (1)$$

Where, G(t) is reduced relaxation function that describes the stress response with time, and $P^e(u)$ is the elastic response. Simon's relaxation function [4],

$$G(t) = 1 - a + ae^{-t/t} \qquad (2)$$

was used. Determination of a and t was accomplished by curve fitting G(t) to experimental data of buttock soft tissue.

**RESULTS**

The demographics of the six subjects are summarized in Table 1.

Table 1. Subject demographics

| Subject Number | Sex | Age | Body Weigh ( kg | Height ( m ) | Body Mass Index | Body Fat ( % ) | Initial Thickn of Bulk Tiss on test site (B-mode) ( cm | Smokin | Neuromuscul Problem |
|---|---|---|---|---|---|---|---|---|---|
| N1 | M | 46 | 90 | 1.78 | 28.74 | 29.66 | 2.67 | Yes | No |
| N2 | M | 41 | 65 | 1.73 | 22.08 | 23.41 | 2.43 | No | No |
| N3 | M | 48 | 90 | 1.80 | 27.94 | 26.62 | 2.89 | No | No |
| N4 | M | 46 | 104 | 1.88 | 29.57 | 27.55 | 2.32 | No | No |
| N5 | M | 4 9 | 74 | 1.68 | 26.35 | 20.6 | 2.10 | No | No |
| N6 | M | 42 | 86 | 1.80 | 26.54 | 25.0 | 2.18 | No | No |

A typical data set of relaxation response is shown in Fig.2. To model reduced relaxation parameters, a and t, force response data in the hold phase was normalized using the peak force. Where, $t_0$ was set as the beginning of the hold phase and $t_\infty$ was set as $t_0$+300*s*.

The results for all subjects are summarized in Table 2 and Fig.3. $R^2$ for curve fitting of the QLV model parameters to experimental data was greater than 0.70. QLV parameter a ranged from 0.067 to 0.328. Parameter t ranged from 44.2 to 164.21. The ratios of standard deviation to mean for a were less than 27%, and less than 75% for t. Intraclass correlation coefficient, ICC (3, 1), values for QLV parameters a and t were greater than 0.72.

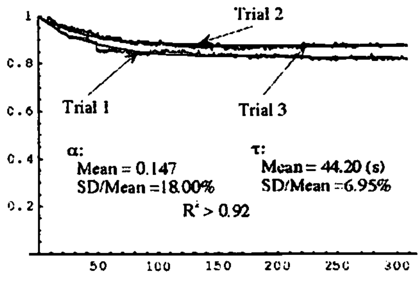



Fig. 2 A typical data set

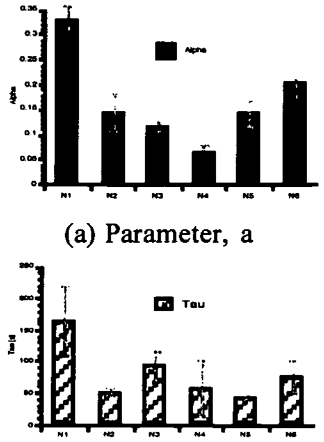
**DISCUSSION**

The results from the ICC analyses demonstrated the reliably and repeatability of our process for in vivo buttock soft tissue assessment using the CASS and the associated test protocol. They also suggested the correlation among the a and among the t from the six subjects.

Judging from the observed values for a and t (Fig.3 and Table 2) Subject N1 appears to be an outlier. Possible explanations for the observed differences are that this subject has a 30 year history of cigarette smoking and higher body fat percentage. If the data from Subject N1 were not included in this study, the ranges of a and t would decrease greatly. Parameter a would range from 0.067 to 0.207 and t would range from 44.2 to 94.17.

Table 2. QLV model parameters for normal subjects

| Subject Number | | a | t | $R^2$ |
|---|---|---|---|---|
| N1 | Mean | 0.328 | 164.21 | 0.95 |
| | SD/Mea | 8.2% | 33.2% | |
| N2 | Mean | 0.146 | 51.92 | 0.87 |
| | SD/Mea | 26.5% | 11.7% | |
| N3 | Mean | 0.115 | 94.17 | 0.88 |
| | SD/Mea | 7.5% | 26.5% | |
| N4 | Mean | 0.067 | 57.84 | 0.76 |
| | SD/Mea | 13.4% | 74.5% | |
| N5 | Mean | 0.143 | 44.20 | 0.92 |
| | SD/Mear | 1 8.0% | 7.0% | |
| N6 | Mean | 0.207 | 76.03 | 0.70 |
| | SD/Mear | 15.6% | 33.9% | |
| ICC | | 0.9334 | 0.7217 | |




(a) Parameter, a

(b) Time constant, t

Fig.3 Comparison of QLV parameters for able-bodied tissues

## ACKNOWLEDGMENTS

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# RESNA Student Design Competition

## RESNA Student Design Competition

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The RESNA 2001 Student Design Competition recognizes the exemplary work of students in the field of Assistive Technology. This year, a total of 24 entries were submitted, from student teams reflecting the interdisciplinary profile of our field.

Designs were judged with respect to the following criteria:

- Appropriateness with respect to real user needs
- Input from intended users or manufacturers
- Innovation and creativity
- Manufacturability and market potential
- Cost to end-user
- Technical competence
- Documentation
- Working prototype or model

Award winners have made a special effort to bring their designs to the Conference. Please visit the Student Design Competition display, and try out their designs.

Continued thanks are in order for the support provided by the Independence Technologies, a Johnson & Johnson Company. Through this support, Independence Technologies helps ensure that individuals with disabilities will have access to the cutting-edge technology, provided by skilled professionals. RESNA expresses thanks to Vice President for Marketing Dave Brown for making this possible.

RESNA's own Susan Leone and Nancy Meidenbauer really set the table for the competition to run smoothly and on-time. Susan's timely guidelines and reminders and Nancy's work in disseminating the papers enabled the process to run flawlessly.

The difficult process of analyzing the designs was carried out with skill by an interdisciplinary panel, who generously devoted the time essential for a thorough and fair review. RESNA is very appreciative of their efforts.

Finally, thanks must go out to all students who submitted entries. Choosing five designs for this year's award was a difficult task.

Glenn Hedman, PE, ATP
Chair, Student Design Competition

# BATTERY TESTER FOR PEOPLE WITH PHYSICAL AND MENTAL DISABILITIES

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## ABSTRACT

The Generations Tadpole Lending Library provides people with physical and mental disabilities low-tech assistive technology devices and toys. There is a need to test batteries, distributed with all loaned toys. Tadpole needed an easily manipulated battery tester with obvious, multi-sensory indicators. A device was built to make testing batteries simpler and more interactive. This device enables many more Tadpole employees to test batteries. It features simple operation, making it easy to use for physically and mentally disabled persons, as well as easy to understand indication of a good or a bad battery. Use of the device is easy enough for the more severely disabled employees of Tadpole to effectively use and understand.

## BACKGROUND

Generations Tadpole is a library that lends and delivers low-tech assistive technology and toys free to consumers, families, and professionals in North Carolina. Employees clean, pack, and ship all items that are lent, and are also responsible for the maintenance of the Tadpole site and customer service [2]. Employees are granted modest pay, based on their productivity. If an employee has more ability, and can perform more work, he will be paid a more than an employee with less productivity potential. Both the employees and the directors of Tadpole want to maximize the working potential, and the salary, of the employees.

With every battery-operated toy or device that Tadpole lends out, they include batteries so that the customer does not have to add them himself. Batteries in returned toys must be tested to determine whether they can be sent out again. Tadpole employees test, sort, and repackage or discard the batteries that come back.

Currently, there are a limited number of employees who are able to test batteries. This is because the current battery tester is difficult to use. It requires much manual dexterity, and awareness to use the device and perceive the outcome. Tadpole wants a tester that is easier to use. More obvious audio, visual, and tactile responses are desired. The method of inserting and removing batteries must also be made easier. It must be operable by employees with very limited motor skills.

## PROBLEM STATEMENT

It is crucial that it be easy enough to use for the intended user. It is also important to help Tadpole employees feel like they can function on the same level as people without disabilities. This battery tester accomplishes both of these goals. The main focuses of the device are easy battery installation and removal, and easily distinguishable responses that appeal to three senses. These goals are designed to provide an easier means of testing batteries than exists currently, and allow a wider range of people to test batteries for employment. Ease of use objectives include the abilities to test all types of batteries, and to orient batteries in either direction, important for the versatility of the device.

## DESIGN AND DEVELOPMENT

Design of the battery tester was broken up into mechanical and electrical aspects. These parts were perfected independently and then combined in a deliverable form. Each part of the project went through many design changes and alterations prior to the final design that was used.

Mechanical obstacles were many. The initially proposed design was completely different than the final design, and allowed batteries to be dropped down a chute, tested, and ejected into the proper bin almost completely independently of the user. This design was modified to accommodate easier battery orientation and easier, more reliable fabrication. In the end, the initial mechanical design was discarded completely in favor of a design that required more user intervention, and provided less opportunity for failure.

Electrical design changes also occurred. An initial design was proposed using comparators to test for battery voltage. Good or bad signal was then sent to a monostable or an astable multivibrator, which would provide the output signal. This design was modified several times to include the use of logic circuitry for triggering the proper response. Additionally, comparators were replaced with optoisolators, to test current from a loaded battery instead of voltage from an unloaded battery. These design changes allowed the final circuitry to be more efficient and more reliable.

The final design consists of a testing unit, a circuitry unit, and 3 peripheral response units. The testing unit allows cylinder batteries to be tested between two spring loaded copper plates in the front of the device. It allows 9V batteries to be tested on two parallel copper strips mounted to the top of the box. Each testing area is equipped with a switch to detect the presence of a battery, regardless of power remaining in it. Figure 1 shows the testing unit before the connection of wires to it. The circuitry consists of four optoisolators, allowing both cylinder and 9V batteries to be tested with either polarity orientation. The outputs of these are passed through a D-Flip-Flop, the output of which is logically combined with outputs of the multivibrators to produce output signals. Three types of outputs exist: LEDs, a vocal response, and a vibrating box. These can all be turned on and off independently. Figure 2 shows the complete setup of the battery tester. The final design optimizes efficiency and utility and accomplishes the stated objectives.

Figure 2. Testing unit (front view) before addition of wires

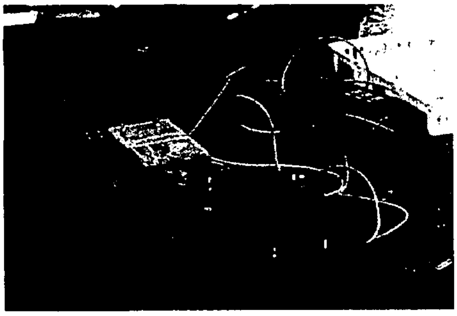

Figure 1. Battery tester (final form) setup

## EVALUATION

The battery tester has been scrutinized at every stage to ensure the most desirable, and reliable design. The physical characteristics and analog features of the device have been introduced to the client and received enthusiastically. The device is functionally and aesthetically successful.

Testing for reliability and accuracy has also been ongoing throughout. Measurement of proper voltage and current thresholds for good and bad batteries occurred often in the electrical design process. The battery quality specifications for this device were obtained using data obtained from the Energizer® website [1], and from the commercially available battery tester currently in use at Tadpole.

Testing of the final device against the currently used device was also done. In 175 tests with both testers, 3 inconsistencies were observed. Retesting eliminated the inconsistency in these circumstances, and the faults were attributed to user error. Based on this testing, and laboratory testing, we can indicate 100% accuracy for the device.

## DISCUSSION AND CONCLUSIONS

The battery tester accomplishes all of the intended design objectives. It succeeds where the currently used device fails. Physical and manual ease of testing batteries is greatly increased. Testing can now be done with the use of only one hand, and the device is large enough not to pose a challenge for those with limited manual control. The indicators for good and bad batteries are vast improvements over the currently used tester. Bright LEDs that glow or flash provide visual response, a recordable voice indicator provides audio response, and a constantly or intermittently vibrating box provides a tactile response. Responses can also be positioned to allow a proximity relation to battery bins. Users will be able to easily manipulate the device and understand the outcome of battery tests using this device.

The device is limited in that it is potentially not usable by all Tadpole employees. Some of the most severely disabled people there may still have difficulty using this device. Accommodation of all employees would require a device that took the testing process completely out of the hands of the used, requiring them to simply drop a battery in a hole.

Any future work would involve a complete redesign of the device that would remove user interaction with the device. The device that has been created accomplishes the objective of being an *easier* to use battery tester that the one currently in use at Tadpole. It is not necessarily the *easiest* to use battery tester that can exist.

The battery tester is a marked improvement over the current battery tester. Not only will it allow more people to be able to test batteries, it will also allow those who currently test them to do so with increased efficiency, confidence, and enjoyment. The manually undemanding design, and the interesting and obvious responses will make for much more successful battery testing.

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## ACKNOWLEDGEMENTS

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# DESIGN OF A MODULAR SENSORY FEEDBACK SYSTEM TO ENHANCE PHYSICAL EDUCATION OF PERSONS WITH DISABILITIES

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**ABSTRACT**
Physical education is an important subject in any student's education, and new teaching methods are sought to incorporate interactivity into the physical education of students with disabilities. This paper discusses the development of a modular sensory feedback system as an interactive approach to physical education activities for students with severe cognitive disabilities, but only limited physical disabilities. The system, composed of a controller box and a customizable sensory cabinet, provides positive sensory stimulation as a result of physical activity. The modular sensory feedback system gives incentive to the students to participate in physical activities, therefore enhancing their overall physical education learning experience, and social activities.

## BACKGROUND

The Rosedale School[2] is a program in the Austin Independent School District providing a positive learning environment for students with severe cognitive, physical and learning disabilities. Rosedale incorporates assistive technology into a functional and community based curriculum. Rosedale tries to provide students with independence and improved self-esteem and experience a greater quality of life through appropriate educational opportunities and quality instruction, as well as abundant care and love. Rosedale has a large number of recreational, entertainment and exercise devices, however, it has been noticed that the students of the school are not very inclined on making use of the exercise devices. The reason being that they are not motivated enough to exercise. Hence the customer viz. Rosedale, wishes for a device that can provide the necessary stimulation and entertainment in order to motivate the student to exercise. The device is designed and manufactured to serve this purpose, in addition to wider application to persons with similar disabilities.

## STATEMENT OF PROBLEM

Of the 110 students currently enrolled in the Rosedale school, roughly 15 percent are ambulatory and are able to participate in traditional physical education learning environments. Within this small group of students, most have profound cognitive disabilities that make verbal communication difficult. When put in the traditional physical education learning environment, the understanding that temporary discomfort is essential for long term benefits is a difficult message to convey. The teachers must make time to devote to individuals when the focus of attention must remain on a group of students. Thus, the design problem here is to develop a product that motivates physical activity while satisfying the customer needs of reconfigurability, low cost, safe environment and reproducibility within the school.

## DESIGN AND DEVELOPMENT

A structured approach to a design problem is extremely beneficial for this type of product development. Firstly, we determined what the customers really wanted through visits to the school and created a sensory profile of the students by passing out survey forms to the teachers and parents. Observation of the currently used methods also gave us valuable insights. Then, using Quality Function Deployment[3], the customer needs were translated into quantified engineering specifications. We decided to break the modular sensory feed back system into two sub-systems, the independent control box and the sensory cabinet, to facilitate embodiment in design. The control box uses information gathered from several student-actuated electrical input devices to control the supply of electrical power to various output devices. The sensory cabinet is a culmination of several visual and tactile sensory output devices arranged in a fashion to provide entertainment to students in a physical education learning environment.

With a good grasp of the customer requirements, we built some proof of concepts to determine the feasibility of our preliminary designs. After incorporating "lessons learned" from the models, we created an alpha prototype which demonstrated the final concept both in terms of functionality and manufacturability. We then presented the alpha prototype to our customers at Rosedale, where it was tested on a few students. Several insights were gained after testing out the alpha prototype. The centrifugal blower we had used to generate an air stream created an unpleasant noise that proved to be a source of distraction. Also, a need was felt to facilitate another form of providing input for students who could not activate the sensory cabinet through a dynamo. We also recognized that proving transparent side panels to the sensory cabinet would enhance the effect of visual stimuli. We also decided to provide multiple outlets so that a variety of devices could be run off a modular control box.

*Figure 1: Control Box*

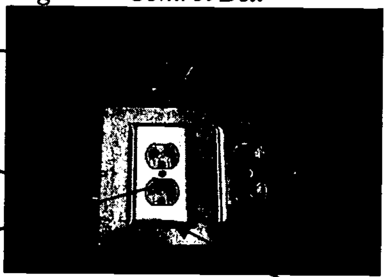
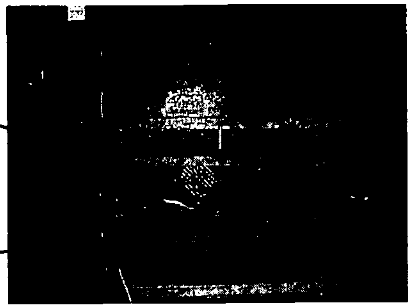



*Figure 2: Control Box Internals*


All of the above changes were incorporated into the beta prototype. As shown in figure 1 and figure 2, the controller box is designed to accept information in one of two methods. The first method utilizes binary input. The input device is a common momentary contact switch, the BIGmack™, designed and manufactured by Able Net Incorporated. The binary input is tied to an adjustable timer circuit with values ranging from a few seconds to five minutes. The second method is through a dynamo, actuated by mechanical rotary input, i.e. the exercise bicycles [4]. This input information is used to activate a relay, which in turn completes a circuit connecting three standard three-prong outlets to standard domestic AC power. This feature allows the control box to be used with a wide assortment of devices using conventional AC power. The sensory profile compiled by us for a number of students showed us specifically which stimuli provoked positive and negative reactions. This information was acquired through teachers and families of the students, as a large number of students encounter extreme difficulty effectively communicating this type of information. The surveys indicated that a strong visual feedback as well as tactile stimulation had a positive affect on the attitude of the student. From this information, the sensory cabinet subsystem was developed.

*Figure 3: "Sensory Cabinet"*


*Figure 4: Lower Box Assembly*




The sensory cabinet, shown in figure 3 and figure 4, is designed as an independent unit to be used with the controller box. The cabinet utilizes a combination of visual and tactile stimulus to create a pleasing environment for the student. The upper portion of the cabinet is the visual display area that is an enclosure that displays hovering and moving balls in a colorfully reflective surrounding. The internal surroundings are illuminated by light filtered through a rotating disc of variously colored gels. The display enclosure is surrounded on three sides by Plexiglas sheeting behind which all viewable surfaces are covered in colorful, reflective holographic paper. In the lower part of the box, a squirrel cage blower that provides a high velocity stream of air directed upwards to cause the balls to hover, and a propeller connected to the disk to rotate, thus rotating the disk. A light source directed at the reflective background is coupled with the rotating color disk to provide an actively changing visual display. The lower section of the cabinet houses a variable speed fan directed forward of the cabinet as a method to provide tactile stimulus to the student.

## CONCLUSIONS

The design of the modular sensory feedback system is an innovative source of attraction and leisure to the students. It also provides the option of driving virtually any kind of device which could be of interest to a particular student and thus motivate him. Thus, it could cater to the therapeutic needs of a large number of students at Rosedale. The device also caters to customer needs such as low cost, ease of use, safe operation and durability.

## ACKNOWLEDGEMENTS

We would wish to express our thanks and gratitude to the students and faculty at Rosedale for providing such a worthwhile and exciting project. We are also indebted to Dr. Rich Crawford and Dr. Kris Wood for the advice, guidance and motivation they provided.

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# AN ASSISTIVE TECHNOLOGY KEY TURNING DEVICE FOR INDEPENDENT ENTRYWAY ACCESS

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## ABSTRACT

Assistive technology focuses on developing devices to help people with disabilities perform meaningful activities and thus improve their quality of life [1]. The device integrates these people into society by removing barriers to their daily activities. This paper presents the development of an assistive technology device for improving accessibility of these people during every day movements, for example operating elevator and opening doors independently. It is very useful specifically for a wheelchair user as it is compact, portable and lightweight.

## BACKGROUND AND PROBLEM STATEMENT

The West Ridge Middle School in Austin, TX is a typical middle school with grades six through eight. Justin, our primary customer at the school, is a typical eleven-year-old kid with one exception. He has rheumatoid arthritis. He is very smart for his age but his illness limits his mobility and range of motion. He uses a wheelchair to get from class to class and must ride an elevator to get from floor to floor several times a day. As West Ridge is a middle school, a key is required to access the elevator to prevent mischievous pre-teens from abusing it. Justin is short in stature. He cannot reach the elevator keyhole and the floor buttons. His illness also prevents him from turning a key easily. The project aims at developing a device targeted at people with operational needs similar to Justin, which could be stored on a wheelchair, would be light enough to hold while operating, and should have a long life.

## DESIGN AND DEVELOPMENT

The team followed a systematic product design and development methodology [2]. The various phases are Task Clarification, Customer Needs Analysis, Functional Modeling, Embodiment, Concept Generation, Concept Selection and Prototyping.

A set of Customer interviews with the primary customer, his parents, therapists and teachers revealed that severe input force and weight limitations on the order of less than a pound exist for our targeted customers. They have limited finger dexterity and flexibility in hand orientation. In fact wheelchair users do not have much space to store the device. These facts posed constraints such as making the device lightweight and portable to meet the force and storage requirements. The customer need "Minimum modifications to wheelchair and elevator" made it mandatory to use human energy input. Functional modeling helped in understanding the functions of the product and it helped us generate ideas for the form of those functions. Verbal and graphical brainstorming methods were used to generate ideas. Using these ideas, the proof of concepts were developed to test their feasibility. Important results of this feasibility testing revealed that it is better to have a direct rotational input as opposed to a linear input converted to rotational.

The architecture of the product shown in figure 1 evolved through all these methodologies. It has a rotational human input at the lower end near Customer's hands. The torque is then transmitted to the higher end, which holds the key and turns it. The higher end needs to hold the key and also transmit the torque to it. Based on this layout, concept variants were then developed graphically. Screening of the Concept Variants helped in final concept selection.

An alpha prototype shown in figure 2 was developed based on the final selected concepts. We tried to adopt off the shelf components as much as possible. This prototype has a fishing pole crank that receives the rotational human input and drives the gearbox. The gearbox transmits the torque in the vertical plane using bevel gears. This torque then gets transmitted to the upper end by a Dremel Tool ™ flexible shaft. Two fishing pole tubes are used to contain the shaft. The key

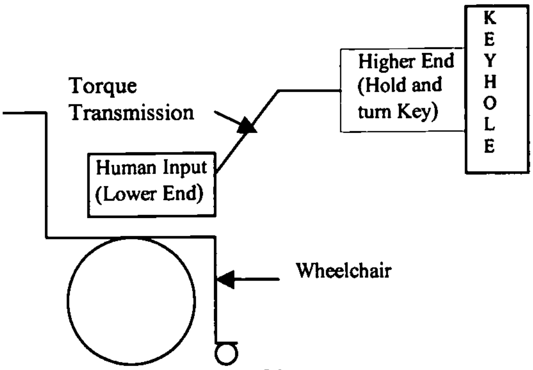


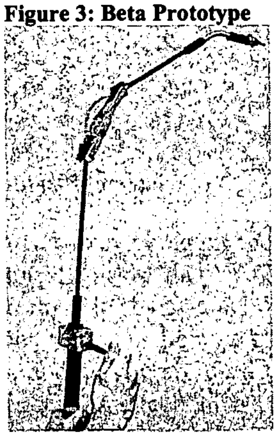

**Figure 1: Product Architecture**

**Figure 2: Justin using Alpha Prototype**

coupler at the top end receives the torque from flexible shaft. Finally the elevator key being gripped between the coupler jaws gets the rotational input and activates the elevator. To assist the user in retracting the key, a slider is provided at the lower end, which pulls onto the flexible shaft, which in turn pulls the key out against a spring fitted in the key coupler. To make the product as lightweight as possible, fishing poles are used as they are made of carbon fiber. Nylon and acrylic are used to make the key coupler and the gearbox. The customer feedback on weight was excellent as it weighed 0.66 pounds but it looked bulky because of the two right-angled carbon fiber tubes. It could not be stored on user's wheelchair. It would not work easily for different heights of the keyholes. Based on customer feedback, the slider for key retraction was not needed as he could very easily pull on the key. But the slider design could be useful for other types of users with translational disabilities.

The development of a beta prototype was driven by customer feedback and the design team's manufacturing experience on the alpha prototype. The final product is shown in figure 3. The rotational input is a crank driven gearbox. To accommodate for various heights, a height adjustment module is provided below the gearbox. Piston movement in a slotted cylinder can raise the whole device through three different heights. Torque is transmitted using the same flexible shaft but instead of fishing poles, which were tapered, round carbon fiber tubes are used to contain it. The device is collapsible which addresses the storage need of users. A two bar linkage was designed for this purpose. The two links are rigidly coupled to the two tubes using delrin couplers. A hinge between the links would collapse the upper structure. A latch, which presses against a torsion spring, achieves easy collapsing and also locking the links during key turning. While collapsed, the flexible shaft displaces into a curved shape between two carbon fiber tubes. The length of the shaft is carefully chosen to avoid binding issues. The key retractor was taken off, as it was

**Figure 3: Beta Prototype**



not needed. This resulted in a smaller key coupler. A cap screw is provided on the key coupler, which grips the key with coupler jaws. Delrin was chosen over Nylon for the key coupler and other small parts like adapters and pins for ease of fabrication. The two links are made out of aluminum "C" channels and have several lighting holes for weight reduction. Higher pitch bevel gears are used to avoid early wear. Once it was fully developed, the primary customer tested the beta prototype by operating school elevators.

## DESIGN EVALUATION

The feedback on beta prototype was encouraging. The primary customer was able to operate the device with ease, but a few problems were recognized. The latch in the two bar linkage mechanism wears out prematurely, reducing the friction at its contact surface with the aluminum link. This collapses the upper structure while turning the key, as it cannot withstand the forces. Attaching sand paper on the contacting surfaces increased this friction. This avoids premature wear and solves the collapsing problem during key turning. The flexible shaft was earlier secured to the adapters by using a single set screw. Now it is secured by two setscrews which safeguard against the slippage of the shaft. The delrin key coupler showed signs of wear and hence aluminum replaced delrin. With these redesigns, the device assumes its final shape and is ready to be delivered to the final customer as well as fabricated for other potential people with similar operational needs.

## DISCUSSION AND CONCLUSION

The resulting final product represents the culmination of a very challenging project with a solution that meets customer needs. It allows the primary customer and other users to independently open doors and access elevators. The design team believes a few more design iterations would make it a more robust device. The future work could be working on the hinged linkage joint making it more durable and adding a door-opening function stated in one of the customer needs. It was designed by the team as a concept proof and could be feasibly implemented in the beta prototype as a future scope. The device would then help users to stay at home on their own.

## ACKNOWLEDGEMENTS

We express our sincere gratitude to officials of West Ridge Middle School, Ms Diane Crawford (Justin's Teacher), Mr. and Ms. Lowe (Justin's Parents) and to the therapists of Justin for providing such an exciting project and assisting during it. We offer our sincere thanks to Dr Kristin L Wood and Dr Richard H Crawford for providing guidance in applying the design methodology. Their inspiration and reviews helped us stay on track. Our acknowledgements would not be complete without extending our deepest gratitude to Justin Lowe, our customer. Without his feedback and comments, this device would not be what it is today.

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# EAR-CHIN STRAP SYSTEM FOR SLEEP APNEA

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## ABSTRACT

The preferred treatment for sleep apnea is the use of a continuous positive airway pressure (CPAP) machine with an attached air hose onto a nasal mask. Only those patients that can remain immobile on their backs are successful candidates for this therapy. The ear-chin strap system maximizes nasal masks by enabling patients to move or turn aiding their compliance with CPAP therapy. The system is acceptable to a wider range of patients because the non-elastic strap system stabilizes the nasal mask, incorporates a chin strap, and manages the air hose.

## BACKGROUND

According to the National Institutes of Health, sleep apnea affects more than 12 million people in the United States (1). Sleep apnea occurs in all age groups and both sexes, although it is slightly more common in men. Sleep apnea affects approximately 4% of middle-aged men and 2% of middle-aged women (2).

Sleep apnea is characterized by extended pauses in breathing, ranging from ten seconds to sixty seconds. For sleep apnea sufferers interrupted breathing during sleep occurs 20 to 30 times per hour. The symptoms of sleep apnea are snoring, gasping during sleep, excessive daytime fatigue, personality changes due to fatigue, and automobile or work-related accidents due to exhaustion. Some life threatening effects of sleep apnea are irregular heartbeat, high blood pressure, heart attack, and stroke (2).

## STATEMENT OF PROBLEM

The nasal continuous positive airway pressure (CPAP) stabilizes breathing by forcing pulses of air into the nose during sleep. Three major problems that exist with the current device deal with the nose mask, the facial straps, and the chin strap.

The nasal CPAP requires that the nose mask maintain a moderate seal on the face. The nasal mask is attached directly to a large bulky air hose. Any head rotation or rolling in bed results in the hose pulling directly onto the mask and straps. If the vertical alignment of the nose mask to the bridge of the nose or upper lip is too tight then it could result in skin injury. The nose mask fit is determined entirely by the tension of the straps.

**Figure 1: Current CPAP system**

The two horizontal straps that attach the nose mask are crucial in determining the mask seal. The straps are often over tightened to compensate for turning away from the air hose line or pressing the mask against the pillow. These straps could cause bruising or irritations of the face, ear, and scalp hair regions. There is an inability to adjust the straps at incremental parts resulting in tension being applied to the whole strap length instead of just at the mask.

The chin strap is crucial to the three strap system because it prevents airflow from passing through the mouth. The chin strap fastens to the top center crown of the head at a 45-degree orientation. Upward pressure on the lower jaw causes potential dental wear and jaw socket problems (3). The chin strap must have substantial tension to prevent slippage.

## DESIGN & DEVELOPMENT

The ear-chin strap system provides extraordinary performance by the additive functioning of separate units, which enhance mask positioning while making allowances for user movements. The ear ring is made of a small, thin, flexible plastic. The ear ring allows the user to feel the sleeping surface, such as a pillow, without a bulky tactile sensation. The ear ring enables individual straps to be adjusted in order to specifically fix any problems with a particular section of the harness. This ear ring eliminates bruising of the scalp and rubbing of the ears associated with the current CPAP. Once the ear rings and straps are initially adjusted to the user, the centering of the ring is quick and automatic and does not change following routine placement.

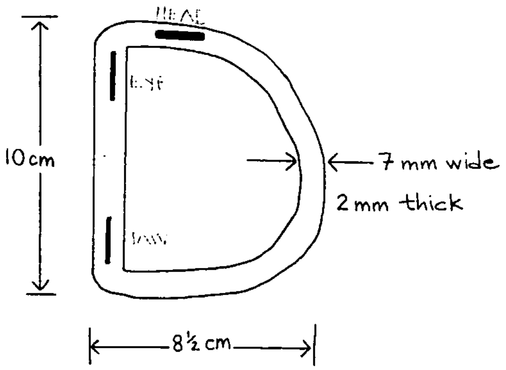


**Figure 2: Ear ring design**

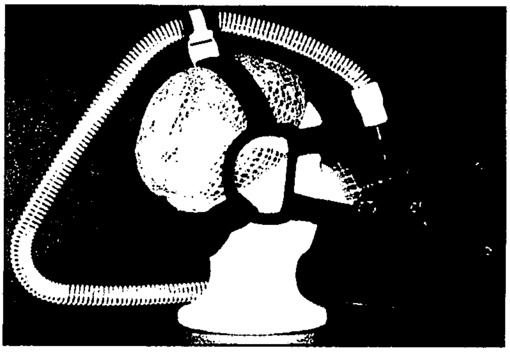

**Figure 3: Ear-chin strap system**

Two horizontal facial straps attach the nose mask to the ear rings. The arrangement of the 4" parallel straps assists in stabilizing the ear-mask aspect of the harness system.

For this design, the chin strap only supports the jaw. The lower parallel facial strap can be used to attach a single, vertical chin strap underneath the chin. One end of the chin strap utilizes a Velcro clip for precise attachment. This chin strap does not compress the jaw like the current nasal CPAP, but merely supports the jaw when lying in bed. The support underneath the chin allows the teeth to be slightly parted with no pressure on the jaw socket. The chin strap acts as an additional vertical control on the lower portion of the nasal mask.

The crown strap loosely connects the top of both ear rings across the crown of the head. The crown strap functions in balancing the head gear structure. Precise Velcro attachment ensures the nose mask is the proper distance from the forehead area. In addition, this attachment allows the air hose to slide along the length of the crown strap as the patient shifts their head. This adaptation results in the CPAP air hose not being directly attached to the mask, which reduces the pulling on the mask when the user rotates during sleep.

The rear strap fits below the nape of the neck to comfortably secure the harness to the head. There is no tension on the head associated with the rear strap because it is only loosely fitted. The rear strap also functions to allow for placement and removal of the harness system.

The ear-chin strap system is the same cost for the manufacturer as the nasal CPAP because the nose mask, chin strap, and additional straps are only altered. The estimated additional cost is for the ear rings that are made by plastic injection molding, which would be less than $10.

## EVALUATION

The initial design used a water polo cap for strap attachment. A water polo cap is made of an elastic, durable material that fits tightly onto the head. The two plastic ear guards that fully encompass the ear were used for strap attachment. Following patient testing on two persons with sleep apnea, it was discovered that the water polo cap device needed some improvement. One patient complained that the cap, although comfortable, significantly warmed the head when worn during sleep. Also, the cap induced a feeling of limitation because it is bulkier than the current nasal CPAP (3). The second user disliked the ear guards fully enclosing the ear (4). The initial design was altered to address these problems. The ear-chin strap system eliminated the cap and modified the ear guards by only using the inner ring. The water polo cap inner ring is egg-shaped but the ear ring used in this sleep apnea device is shaped like the letter "D". With this new device, both patients were able to comfortably move in bed while retaining the suction of the nose mask. The harness can be placed on the head or removed in a matter of seconds. Importantly, no adjustments have been needed after the initial setting. The two patients have adopted the ear-chin strap system as their method of treating sleep apnea.

## DISCUSSION

The current nasal CPAP mask harness and the separate chin straps are limited in functional capabilities. The present harness and chin strap are single attachments that rely solely on compression and strap tension to maintain placement.

The ear-chin strap system has several innovative features. The nose mask and the chin strap are incorporated into the harness structure. The chin strap keeps the mouth closed without placing pressure on the jaw socket. A flexible attachment to the crown strap is used to further align the air hose and secure mask placement. The harness enables adjustments to be effected at a number of places throughout the system because each strap attachment site uses Velcro. Unlike the present nasal CPAP, the ear-chin strap system does not use strap tension to maintain placement. The ear-chin strap system benefits the user psychologically and physically which promotes long-term CPAP compliance to a wider range of patients.

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## ACKNOWLEDGMENTS

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# ACTIVITY CENTER DESIGN

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ABSTRACT

Specialty needs programs at public schools are more demanding on teachers since they must help students with a wider range of problems than a normal academic class. Additionally, the teachers need special tools to help these students and cannot afford the high cost of catalog assistive technology devices. A design was sought out that could minimize the material cost of an activity center while maximizing the number of activities and types of users. The design also had to be simple to fabricate so that the school could reproduce the activity board or additional activities.

## BACKGROUND

The current design is targeted for three users at Rolla Public High School. Two of the three users have Down syndrome and one is recovering from multiple brain aneurysms. They need training activities to enhance their motor skills and multi-sensory skills. One of the users can use only one hand to perform activities. This constraint was crucial in designing the size and shape of the final design. There were also other needs for the users including the need for lights and sounds and as many activities as possible in addition to having a colorful design. A manufacturing need that was considered was that the school wanted to be able to make another activity board or additional activities.

The drive behind this design problem was that the public schools could not afford an activity center for its special needs students. Current products can incorporate several activities and store them, but they are large, up to the size of a decent workbench, and cost approximately $1900. Currently the public school students must work on activities that are laid out on a horizontal surface like a table or a board on a wheel chair. The school wanted to have activities mounted vertically so that it would be easier for students to see and use the activities.

## STATEMENT OF THE PROBLEM

The goal of our design is to create a device, which will enhance the motor skills and dexterity of students who have a limited range of motion. This enhancement will be achieved through the use of every day activities, which will be arranged modularly on an activity board so that different activities can be used at different times and in different arrangements and the user can reach all activities with one arm. In addition, it should be possible for the school to fabricate such a device with the use of off-the-shelf materials and a high school wood shop.

## RATIONALE

The rationale behind creating the activity board is that the school needs an inexpensive solution to meet their need for a device, which can enhance a wide variety of skills so that it will meet the specific needs of more than one student. The school also wanted a device that they could fabricate using their wood shop so that they could expand the amount of activities or even make another activity board.

DESIGN

The design first began by gathering the customer needs from the teachers, physical and occupational therapists, and family members. By using interview methods some basic geometric constraints were developed for the activity board and some activity candidates were discovered. By using a questionnaire containing over forty activities and circulating it throughout the school, a list of primary activities was developed. Next, a black box was developed, which stated the overall function of the design, to enhance multiple activities. After that, a functional model was developed and modules were identified. A morphological matrix was developed so that solutions to the sub-functions of the functional model could be brainstormed. Grouping solutions from the morphological matrix sub-functions generated concept variants. Eight concept variants were generated in all. These eight concepts were first screened using a Pugh Chart. The best three concepts from the Pugh Chart evaluation were more closely scrutinized using a Decision Matrix. From the Decision Matrix, one concept was selected. An alpha prototype was fabricated from Styrofoam for the proof of concept. The proof of concept proved that an activity board could be made with the correct curve for the front surface. More analysis was done on the final concept to make certain the design would be stable, durable, and easy to manufacture. The Bill of Materials and the assembly plan were developed and the beta prototype was constructed. The beta prototype was brought into the school to make sure all of the customer needs were met and to take suggestions from teachers for improvements that could be made to the final design. Final modifications were made to the beta prototype in preparation for delivery. Finally, considerations were made as to the modifications of the final design that would be necessary to enable the activity board to be mass-produced.

Various innovations in the designed product were achieved. The major innovation was to come up with a wrap around surface so that all activities are accessible with one arm while eliminating classroom distractions. The final activity board design is durably painted and contains no sharp edges or surfaces. The bottom of the board was coated with a non-slip surface to insure safety. The back of the activity board also serves as a cabinet, which can store all of the activity modules. The depth of the cabinet makes the activity board stable when the students use it on the edge of the table. All the modules are painted in different colors and include inviting activities selected by the teachers themselves. The activity modules also incorporate multi-sensory activities, which use sound and light to enhance motor skills. The activities themselves are self-contained and can be arranged in many different configurations. The primary activity board can accommodate up to six activity panels.

DEVELOPMENT

Another avenue for development is the possibility of expanding the design so that two to four students could use the activity board at the same time. The current model has one curved board that can accommodate six activities and two side panels that can hold two activities. By expanding the design to incorporate two curved boards, a platform design arises where a producer can sell a double or quadruple user activity center. By making one activity board with two curved surfaces, several different arrangement possibilities develop.

EVALUATION

The completed activity board consists of one cabinet and ten activity panels. Nine of the activity panels are one-foot squares and one of the activity panels is a one-foot by two-foot rectangle. All ten of the modules can the stored in the cabinet behind the curved front surface.

The ten activity panels incorporate the use of bolts, door locks, doorknobs, lights, sounds, colors, sorting, matching, drawing, writing, fasteners, buttons, buckles, and shoelaces. The activity panel involving threaded bolts, nuts, and washers can help to "improve unilateral and bilateral fine-motor coordination and further develop pronation and supination (1)." The activity panels involving door locks, doorknobs, and light switches is useful in helping to develop daily living skills and encourage fine- and gross-motor skills. The activity panel involving buttons, snaps, zippers, buckles, and shoelaces is designed to improve bilateral manipulation, help teach fine-motor fastening skills, and to aid in training for single-handed use. All of the activity panels included with the activity board will help the teachers to promote and improve the fine-motor and perceptual skills of all of the users. (1)

The alpha prototype, a Styrofoam model, was delivered to the school to verify size and accessibility. The beta prototype, a painted wooden model with working activities, was delivered to the school for final analysis. The users were very excited to see the product in a final state and anxious to use this product in a classroom environment. The teachers were very exited about the wide range of activities in addition to the fact that they could easily add more activities. A suggestion was made to alter the activity board to accommodate two additional users on the vertical sides of the cabinet. This change was easily achievable by attaching additional inserts to each side of the cabinet. These additional inserts will accommodate up to four more activity panels. The activity board in the altered state can occupy up to three users and ten activity panels.

## DISCUSSION

The production of this activity board has provided a great benefit to the users. S&S Opportunities magazine (1) has for sale an activity center consisting of a cabinet and 11 activities at $1889.00, weighing 300 pounds in total. The cabinet can be purchased separately for $1072.00, weighing 225 pounds and measuring 39"H x 27"W x 49"L. The activities can also be purchased separately for an average cost of approximately $67.00. The end result of this project has yielded an activity center consisting of a cabinet and 10 activities for $340.00, weighing 66 pounds in total. The cabinet alone weighs only 42 pounds and measures 30"H x 22"W, x 36"L, which allows for two people to easily move the activity center wherever needed. The average cost of producing one activity panel is approximately $20.00. As can be seen, this has been a significant cost and weight savings for the users.

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## ACKNOWLEDGMENTS

Our group would like to thank the following people for their input, support and guidance throughout this project – Dr. Dan McAdams, Dr. Rob Stone, Ms. Kadi Haslag, Ms. Susan Arthur, Ms. Kathie Wolfert, and the students at Rolla High School.

# RESNA Student Scientific Paper Competition

## Student Scientific Paper Competition
**Sponsored by Whitaker Foundation**

On the following pages, you will find the five award-winning papers for the seventh annual RESNA Student Scientific Paper Competition. The student awardee is listed as the first author on each of the papers. 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 student design competition.

The winning papers are presented in a special session during the RESNA 2001 Conference. This session provides a unique forum that, in addition to highlighting student research activity, brings together papers on diverse topics for presentation. 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.

I would like to sincerely thank the review committee for this year's competition: Francie Baxter, Allen Hoffman, Geoffrey Fernie, Dan Jones, Jane Huggins, Heidi Koester, Rich Mahoney, Simon Margolis, Tariq Rahman, Steven Reger, Larry Schneider, Jon Schuch, Machiel Van der Loos, and Jack Winters. They faced very difficult decisions in choosing the five winners as most of the papers were deemed meritorious.

On behalf of RESNA, I wish 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 2002 RESNA Student Scientific Paper Competition.

Richard Simpson, PhD ATP
Chair, RESNA Student Scientific Paper Competition

# SCAPULA ORIENTATION IN A VIRTUAL WHEELCHAIR PUSH

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**ABSTRACT**
Recording scapula motion *in-vivo* during wheelchair propulsion has been hampered by the large amount of skin movement over the bone. Using a digitizing probe, the three-dimensional position of the scapula was recorded on 10 manual wheelchair users in six different statically held positions along the pushrim. A local coordinate system analysis was used to compute mean scapula angles relative to the torso in anatomical terms. As subjects moved incrementally along the pushrim, the scapula downward rotation and protraction angle increased while the forward tipping angle decreased. Investigations on scapula position and orientation in wheelchair propulsion may help explain why many individuals who use manual wheelchairs develop shoulder injury.

**INTRODUCTION**
Nearly half of the manual wheelchair user (MWU) population will develop shoulder pain or pathology (1). Research has shown that propulsive forces are associated with evidence of shoulder injury (2) but additional research is needed to understand specific biomechanical predictors of injury. Movements of the shoulder result from the complex interplay between several bony articulations, muscle forces and ligament restraints. The shoulder is comprised of four joints: glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic. The glenohumeral joint constitutes for a majority of the overall motion due to its ball-n-socket joint configuration. Most biomechanical models used to describe shoulder motion and loads during wheelchair propulsion focus primarily on glenohumeral joint mechanics due to the complexity of modeling multiple joints of a closed link system. Glenohumeral joint motion is relatively easy to record during propulsion by tracking the movement of skin markers or marker trees placed on the humerus with three-dimensional (3D) motion analysis cameras or films or video. The most obvious problem with this method for recording scapula motion is that the scapula is moving underneath the skin. Thus, 3D scapula kinematics have mostly been based on cadaver data. Electromagnetic tracking devices and fluoroscopy are becoming increasingly more popular for tracking scapula motion during shoulder activities. However, magnetic interference and receiver confusion are threats to using electromagnetic devices and radiation exposure is a concern in fluoroscopy studies.

A safe, common, and sufficiently accurate technique although requiring static recordings involves the use of a digitizer probe or palpator. This device can be used to record the static 3D position of its end point when placed directly on palpable anatomical landmarks on the scapula. The purpose of this study was to describe the 3D orientation of the scapula in various stages of the propulsion phase. When injury occurs either through a single traumatic event or through a series of repetitive microtrauma, multidirectional instability of the shoulder may result. Hence, investigating scapula kinematics will help provide a better knowledge of the forces acting at the shoulder and aid in improving the models used to study shoulder biomechanics in wheelchair propulsion research.

**METHODS**
*Subjects.* Ten experienced MWUs consisting of 8 men and 2 women with a spinal cord injury (SCI) at the T-2 level or below provided informed consent to participate in this study. The average age, years with SCI, and mass were 40.7 $\pm$ 9.2 years, 16.9 $\pm$ 8.6 years, and 80.6 $\pm$ 13.7 kg, respectively.

*Experimental Protocol*: Subjects' were tested in their own personal wheelchairs and brakes were activated to prevent movement of the wheelchair. Since three subjects had significant right side shoulder involvement, the analysis was performed on the left side for all subjects. A rigid body made of carbon fiber composite and consisting of three non-collinear IRED markers of the OPTOTRAK motion analysis system (Northern Digital, Inc.) was attached to the sternum to measure torso rotation. A digitizing probe was designed and fabricated according to specification by Northern Digital (Figure 1). Six-markers were mounted, three on each side, to maximize their visibility by the two bilaterally placed OPTOTRAK cameras. Subjects were tested in six randomly presented hand positions: -30°; -15°, 0°, +15°, +30°, +60° with 0° the top of the pushrim and negative angles behind the top. At each angle, 3D positions of the torso markers relative to the global reference frame were recorded and the following three points on the scapula were digitized: angulus acromialis (AA); trigonum spinae (TS); and the angulus inferior (AI) (Figure 2). During the recordings no movements of the subjects were allowed.

Figure 1: Digitizing Probe

*Data Analysis*: Local coordinate systems (LCS) were constructed at the scapula and torso. For the scapula (origin at AA), the z-axis, Zs, pointed from AA to TS; the x-axis, Xs, perpendicular to the scapular plane (AA, TS, and AI), and the y-axis, Ys, perpendicular to Xs and Zs (Figure 2). For the torso, y-axis, Yt, pointed upward along the longitudinal axis of the sternum x-axis, Xt, perpendicular and anterior to the plane of the sternum, and z-axis, Zt, perpendicular to Yt and Xt. The scapula and torso orientation (${}^{G}R_S$ and ${}^{G}R_T$, respectively) as measured in the different positions with respect to the global reference frame were:

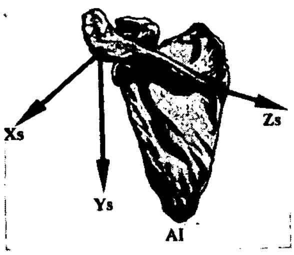


Figure 2: Scapula local coordinate system

$$ {}^{G}R_S = \begin{bmatrix} i_{X_S} & i_{Y_S} & i_{Z_S} \\ j_{X_S} & j_{Y_S} & j_{Z_S} \\ k_{X_S} & k_{Y_S} & k_{Z_S} \end{bmatrix} \quad \text{and} \quad {}^{G}R_T = \begin{bmatrix} i_{X_T} & i_{Y_T} & i_{Z_T} \\ j_{X_T} & j_{Y_T} & j_{Z_S} \\ k_{X_T} & k_{Y_T} & k_{Z_T} \end{bmatrix}. $$

The orientation of the scapula in any recorded position relative to the torso (${}^{T}R_S$) was computed from the following:

$$ {}^{G}R_T \bullet {}^{T}R_S = {}^{G}R_S \quad \Longrightarrow \quad {}^{T}R_S = {}^{G}R_T^{\tau} \bullet {}^{G}R_S $$

where $R^{\tau}$ represents the transpose of a matrix. The rotation matrix, ${}^{T}R_S$, is comprised of three rotation matrices consisting of three Euler angles. The rotation order was consistent with the International Shoulder Group's Standardized Protocol for measuring scapula joint rotations (3). For the scapula, the first rotation (α) was around the Ys-axis and can be interpreted as pro/retraction. The second rotation (β) was around the rotated Xs'-axis and represented upward/downward rotation. The final rotation (γ) was about the rotated Zs''-axis and can be described as forward/rearward tipping. Thus, the resulting decomposition for an YXZ order of rotation was:

$$ R = {}^{T}R_S = R_Y(\alpha) \bullet R_X(\beta) \bullet R_Z(\gamma). $$

The following equations were solved for the scapula rotation angles:

$$ \alpha = a\tan\left(\frac{R(3,1)}{R(3,3)}\right); \quad \beta = a\tan\left(\frac{-R(2,3)}{\sqrt{R(1,3)^2 + R(3,3)^2}}\right); \quad \gamma = a\tan\left(\frac{-R(2,1)}{R(2,2)}\right) $$

Mean torso flexion and scapula angles were determined across subjects for each position (Table 1).

**RESULTS**

Overall mean scapula angles were smallest in upward/downward rotations and largest in forward tipping. At the beginning of the push, the scapula was rotated slightly downward, minimally protracted, and maximally tipped forward. The scapula continued to rotate downward until the most forward position on the pushrim was reached where it was found to rotate slightly upward or lateral. As subjects moved forward along the pushrim, the protraction angle increased while the forward tipping angle decreased. Inter-subject variability was largest for the measured up/downward rotations as well as for the tip angle in the most forward hand position.

**DISCUSSION**

The findings of this study represent a clinically relevant description of scapula angular orientation during a virtual wheelchair push. The small magnitudes and differential in scapula angles between positions is not unusual as the majority of scapula movement occurs at a much higher degree of humeral elevation than what is generally observed during propulsion. Increased downward rotation, increased protraction and decreased forward tip angles was the general pattern observed. A similar study by Veeger *et al.* on four male unimpaired individuals showed similar mean forward tip angles, but larger up/down and protraction angles, however, specific scapula angles at each hand position were not reported to enable for a direct comparison across studies (4). The differences between studies may be attributed in part to the diversification in anthropometry among the participants in this study which is more representative of the MWU population. This information will be useful in identifying if complex biomechanical shoulder models should incorporate scapula kinematics or if they can be simplified to include only glenohumeral joint mechanics. Moreover, reports have shown that scapula kinematics will be different between persons with and without shoulder impingement (a common shoulder problem among MWUs). Thus, scapula kinematics and its relationship to propulsion may provide further insight into the development of shoulder pathology.

Table 1: Mean scapula angles and torso flexion angle (N=10) in degrees are shown for five static positions. (± standard deviation)

| *Positions* | *Torso Flex* | *Down(+)/Up(-)* | *Protraction* | *Forward Tip* |
|---|---|---|---|---|
| *-30°* | -6.7° (7.3) | 1.5° (4.7) | 15.0° (3.7) | 21.9° (6.0) |
| *-15°* | -9.0° (8.1) | 2.1° (6.6) | 15.1° (5.3) | 19.1° (8.7) |
| *0°* | -7.9° (9.2) | 4.3° (6.6) | 16.1° (4.1) | 19.2° (7.3) |
| *+30°* | -5.8° (7.2) | 4.4° (9.0) | 16.2° (3.3) | 17.2° (6.5) |
| *+60°* | -3.3° (7.7) | -0.7° (4.6) | 18.2° (4.1) | 14.1° (16.3) |

**CONCLUSIONS**

This study provides a detailed description of scapula orientation in a simulated wheelchair push. Further research is needed to characterize dynamic orientation of the scapula during propulsion.

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# REPEATABILITY OF DETERMINING EFFECTIVE YOUNG'S MODULUS OF BUTTOCKS SOFT TISSUE ACROSS MULTIPLE SUBJECTS

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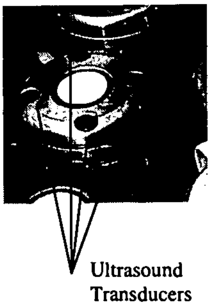
## ABSTRACT
Characterization of the intrinsic mechanical properties of soft tissue is essential to the study of tissue loading and pressure ulcer etiology. To this end, an *in vivo*, *in situ* method was developed to determine the Young's Modulus for the soft tissue of the buttocks. The Young's Modulus was determined through a linear regression of force-deformation data taken from the buttocks of able-bodied subjects seated on the Computer-Automated Seating System (CASS) [1]. Our study objective was to evaluate the repeatability of assessing the effective Young's Modulus (E) in multiple able-bodied subjects. After examining 6 able-bodied subjects, our method of assessing E was found to be repeatable.

## BACKGROUND
25% of the 200,000 individuals with spinal cord injuries in the United States develop pressure ulcers each year [2]. Pressure ulcers are not only a physical and emotional burden on the injured, but also result in high medical costs. An understanding of the mechanical response of the tissue to external loading is necessary to understand the mechanisms leading to pressure ulcers as well as identify the risk factors. Such mechanisms cannot be obtained without a clear understanding of the more basic mechanical properties of the tissue.

## RESEARCH QUESTION
This study examines the repeatability of characterizing the elastic response of buttocks tissue to indentation. Multiple subjects were examined to evaluate the repeatability of our proposed *in vivo*, *in situ* method of assessing tissue properties for a given subject.

## METHODOLOGY
A flat-ended, cylindrical indenter containing force, pressure, tilt, and ultrasonic transducers was used to obtain data. The CASS, shown in Fig. 1, is an array of such sensors [1]. For this experiment, only one indenter was active. Each subject was placed on the CASS with the active element positioned 4 cm distal to the ischial tuberosity and centered under the femur. Prior to measurement, the site was preconditioned with cyclic loading for 3 minutes. Indentation depth was 20% of the bulk tissue thickness and tissue layer deformations were continuously monitored during testing using ultrasound echo tracking techniques. The indentation rate was controlled by the automated indenter to assure repeatable loading conditions. Able-bodied subjects between the ages of 40 and 60 years of age were tested.

*Fig. 1 CASS*



Previous studies have shown that an approximate elastic response for soft tissue can be modeled by applying a scaling factor to a force-deformation curve from a flat-ended cylinder indenting tissue [3,4,5]. The scaling factor is a function of Poisson's ratio, the initial thickness of the tissue, and the diameter of the cylinder used for indention. Assuming a Poisson's ratio of .45 with a constant indenter diameter, the scaling factor becomes a function of the tissue thickness alone. This gives the equation for the effective Young's Modulus, E, as

$$E = \frac{1}{\mathrm{K}(h)} \frac{P}{w} \qquad \text{(A)}$$

where $h$ is the initial tissue thickness, $\mathrm{K}(h)$ is the scaling factor, $P$ is the force, and $w$ is the deformation.

## RESULTS

Multiple trials were run on each subject and the force-deformation response was plotted. Linear regression was used to fit the data. An example of typical force-deformation response data and regression is shown below (Fig. 2).

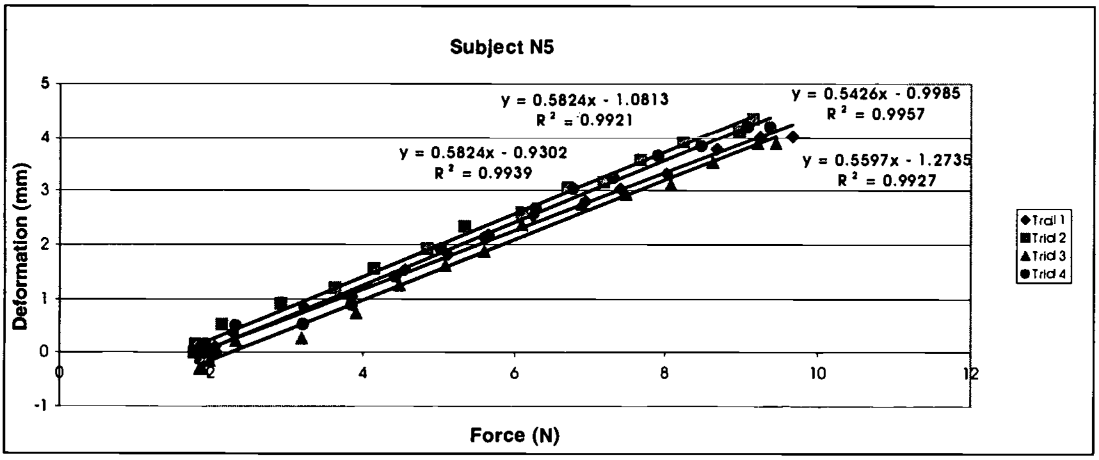



*Fig. 2 Typical Subject Force-Deformation Response and Linear Regression*

## DISCUSSION /CONCLUSIONS

As can be seen in Fig. 2, the force-deformation curve exhibits a high degree of linearity, with $R^2$ values ranging from .9268 to .9958 for subjects N3 to N6. Not all subjects exhibited this degree of linearity however, and contributing factors such as subject movement, muscle tension, indenter misalignment, and loss of echo triggering while collecting data could have led to the more non-linear responses seen in N1 and N2. The influence of these various factors on the elastic response is currently under investigation.

Effective Young's Moduli ranged from 14 to 76 kPa among the different subjects. These values correspond very well with the previous work on the lower limb done by Zheng and Mak, who reported a range of 10.4 to 89.2 kPa for E [4]. The average effective Young's Modulus for each subject along with the standard deviation is shown in Fig. 3. The standard deviation ranged from .6

to 2.5 kPa in subjects N3 to N6, indicating a highly linear force-deformation response is necessary to obtain a repeatable effective Young's Modulus. The first two subjects, N1 and N2, had standard deviations of 20 and 12 kPa respectively. Subject body composition, positioning, loss of signal, and other factors are currently being investigated to explain this inconsistency.

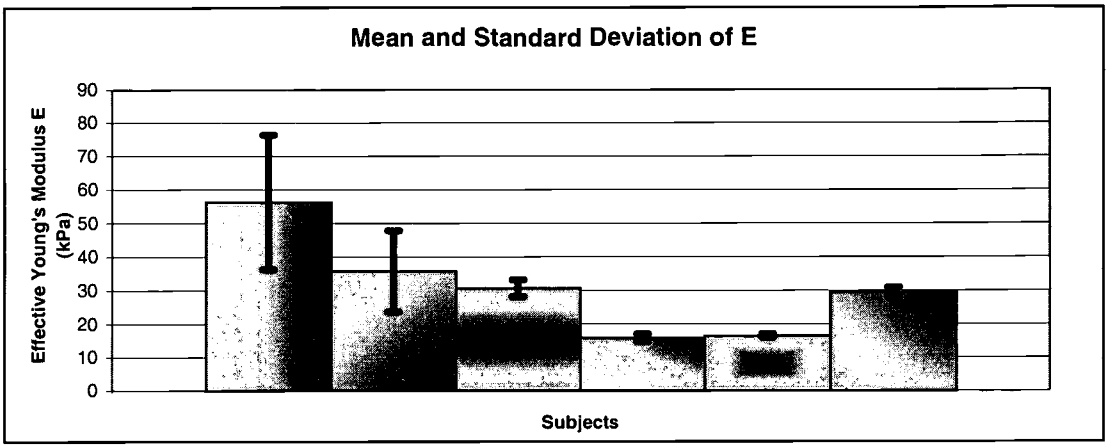



*Fig. 3 Mean and Standard Deviation of the Effective Young's Modulus for 6 Able-bodied Subjects*

The repeatability of our test method provides the foundation for further investigation of the influence of age, gender, body composition, and other factors on soft tissue properties.

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**POWER AND CONTROL SYSTEM TESTING OF FIVE DIFFERENT TYPES OF POWER WHEELCHAIRS**

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## ABSTRACT

The purpose of this study was to test power and control systems of five different models of power wheelchairs according to Section 14 of the ANSI/RESNA standards. Although there is a significant need for one, currently, no comparative study exists among different models of power wheelchairs. Results indicate there are differences in the performance of the power and control systems of tested chairs. All chairs failed the battery connection and circuit protection diagram test. Two of the Quickie chairs could be driven while the battery charger was still connected to the battery. All three Permobil chairs failed the fuse, non-powered mobility, and safety guard tests. Invacare's Action Storm Chair failed the reverse polarity test and as a result, the controller was damaged.

## BACKGROUND

Wheelchair standards in the United States are voluntary. The US Food and Drug Administration does accept test results from the American National Standards Institute and Rehabilitation Engineering and Assistive Technology Society of North America (ANSI/RESNA) (1). Wheelchair standards set by ANSI/RESNA are designed to provide tests useful for the comparison of wheelchairs. Manufacturers do not readily provide the results of these tests to the public. Therefore, the need for a comparative study among various power wheelchairs is apparent, and currently, there is no such study available to the public.

The safety of a wheelchair's electrical systems is important for a user. Section 14 of the ANSI/RESNA standards calls for the testing of the power and control systems of manual wheelchairs. It sets forth the minimum requirements for the protection of a wheelchair user during normal, abusive, and failure conditions (2). Wheelchairs used in this study were purchased from the dealers without their knowledge that the chairs would be tested. This insured that the chairs tested would be similar to the ones purchased by consumers with no special adjustments.

## RESEARCH QUESTION

Are there any differences in performance when the power and control systems of five different types of electric wheelchairs are tested according to Section 14 of the ANSI/RESNA standards?

## METHOD

Three wheelchairs of five different models were selected for the study. These included: the Sunrise Medical Quickie P200, the Invacare Action Storm, the Everest & Jennings Lancer 2000, the Permobil Chairman, and the Pride Healthcare Jazzy. All chairs used a Penny & Giles controller (model numbers: D49323, D49637, D49307, D49363), except the Invacare, which used an Invacare MKIVA controller (model number: 1065944).

WHEELCHAIR CONTROL SYSTEM TESTING

Section 14 of the ANSI / RESNA standards is divided into five main test parts: Part 6 tests the electrical systems, Part 7 is a non-powered mobility test for the automatic braking system, Part 8 is a safety guard test, Part 9 tests the battery chargers, and Part 10 determines the forces required to operate control devices. According to the standards, any modifications made to the wheelchair during a test must be reversed before continuing on to the next test.

Equipment used while performing the tests included: a direct current source that provides a voltage 1.25 times the nominal voltage of the battery set of the wheelchair; a standard jointed test finger; a standard unjointed test finger capable of being attached to a force measuring instrument; a force measuring instrument capable of measuring forces in the range of 0 to 100 N; a test circuit which included a DC ammeter and a 10kΩ resistor; and two circuit breakers rated at 50 and 100 amps.

**RESULTS**

The following table represents how individual chairs performed during each section of part 14 that was tested. An "F" indicates failures and chairs that passed the tests are represented with a "P". Blank spaces indicated tests that need to be completed.

Table 1

| Wheelchair | 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | 6.7 | 6.8 | 6.9 | 6.10 | 6.11 | 7.3 | 8.3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Invacare #1 | ***F*** | ***F*** | P | P | P | P | P | P | P | ***F*** | P | P | P |
| Invacare #2 | ***F*** | ***F*** | | P | P | P | | P | | | | P | P |
| Invacare #3 | ***F*** | ***F*** | P | P | P | P | P | P | P | | P | P | P |
| Quickie #1 | ***F*** | ***F*** | P | P | P | P | P | | ***F*** | P | P | P | P |
| Quickie #2 | ***F*** | ***F*** | P | P | P | P | P | | ***F*** | P | P | P | P |
| Quickie #3 | ***F*** | ***F*** | P | P | P | P | P | | P | P | P | F | P |
| E & J #1 | ***F*** | ***F*** | P | P | P | P | P | P | P | | P | P | P |
| E & J #2 | ***F*** | ***F*** | P | P | P | P | P | P | P | | P | P | P |
| E & J #3 | ***F*** | ***F*** | | P | P | P | P | P | | | | P | P |
| Permobil #1 | ***F*** | ***F*** | P | ***F*** | P | P | P | | P | P | | ***F*** | ***F*** |
| Permobil #2 | ***F*** | ***F*** | P | ***F*** | P | P | P | | P | P | P | ***F*** | ***F*** |
| Permobil #3 | ***F*** | ***F*** | P | ***F*** | P | P | P | | P | P | P | ***F*** | ***F*** |
| Jazzy #1 | ***F*** | P | P | P | P | P | P | P | P | P | P | P | P |
| Jazzy #2 | ***F*** | P | P | P | P | P | P | P | P | P | P | P | P |
| Jazzy #3 | ***F*** | P | P | P | P | P | P | P | P | P | P | P | P |

6.1 – Battery and circuit connection
6.2 – Color and marking of battery wires
6.3 – Electrical isolation of wheelchair
6.4 – Safety when replacing fuses
6.5 – Interchangeability of connectors
6.6 – Attachment and positioning of wiring
6.7 – Protection from non-insulated electrical parts
6.8 – Short circuit protection
6.9 – Safety when charging batteries
6.10 – Reversed polarity at batteries
6.11 – Controller overvoltage test
7.3 – Non-powered mobility test
8.3 – Safety guard test

All chairs failed the battery connection and circuit protection diagram test. This was primarily because none of the manufacturers included the rating of the fuses as part of their diagrams. Only the Jazzy chairs' battery connection wires were permanently marked with "+" or "—" symbols. Initially, none of the Quickie chairs were drivable while connected to their respective chargers. However, when the charger was still connected to the chair but disconnected from the power supply, two of the Quickie chairs could be driven in all directions. All three Permobil chairs failed the fuse, non-powered mobility, and safety guard tests. Permanent damage to the controller resulted when one of the Invacare chairs underwent the reverse polarity test.

## DISCUSSION

The safety of a power wheelchair's power and control system is important; however, regardless of what type of system is used, it will eventually fail over time. Therefore, the ability of a power wheelchair to fail safely is equally important (3). Injury from electrical shock or fire could result from a wheelchair's electrical system being wired incorrectly or damaged from normal use. More than likely, a chair's electrical system would fail, and simply render the chair useless without causing injury to the user. However, this could result in expensive parts having to be replaced on the wheelchair.

The previous example is similar to what happened when one of the Invacare chairs underwent the reverse polarity test. When examined closely, no circuit protection device for the controller could be found on the chair. This resulted in a transistor on the board being damaged and having to be replaced.

Further tests include completion of Part 14 tests for all 15 of the selected power wheelchairs.

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# MODIFICATION OF HYBRID III TEST DUMMY FOR USE IN WHEELCHAIR STUDIES

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## ABSTRACT

Test dummies provide an ethical and practical alternative to subjects when assessing the risks and prevention mechanisms of tips and falls in controlled studies; however, are only as enlightening as they are similar to the population for which they represent. The goal of this study was to develop a low speed, low impact test dummy for use in the study of the prevention of tips and falls from wheelchairs. Modifications were made to a Hybrid III test dummy in order to provide more motion in the hip joints, and therefore, more realistic trunk motion. An accurate dummy for use in wheelchair/rider tests will enhance understanding of how the user, wheelchair, and environment interact, and may lead to greater mobility with less risk of injury.

## INTRODUCTION

There are approximately 1.5 – 2 million full-time wheelchair users in the United States. An estimated 3.3% per year experience a serious wheelchair-related accident (1). About 70% of these accidents are attributable to tips and falls (1&2). Despite the increasing trend in wheelchair accidents every year, there is little literature on the cause and prevention of these accidents. Test dummies provide an ethical and practical alternative to subjects when assessing the risks and prevention mechanisms of tips and falls in controlled studies; however, are only as enlightening as they are similar to the population for which they represent.

The purpose of this study was to develop a low speed, low impact test dummy for use in the study of the prevention of tips and falls from wheelchairs. An accurate dummy for wheelchair test purposes will enhance understanding of how the user, wheelchair, and environment interact, and may lead to greater mobility with less risk of injury.

## METHODS

*HTD Modifications:* A 50$^{th}$ percentile Hybrid III anthropomorphic test dummy (HTD) was used to simulate the occupant of a power wheelchair. The HTD series is an industry standard in vehicle crash testing and comes equipped standard with a seated pelvis and curved lumbar spine so the HTD can assume an "automotive seated position"(3). When investigating the nature of power wheelchair accidents, the occupant may not necessarily remain in a seated posture in the occurrence of a fall. To accommodate for this, a standing "pedestrian" pelvis with the accompanying straight lumbar spine was employed in place of the seated pelvis with curved lumbar spine. Vinyl coated foam "tissue" was removed from the inner thighs of the HTD to allow for a non-interference fit during seated posture (Figure 1A). Further modifications were made based on the hypothesis that bending in a forward fall from a wheelchair occurs mostly from flexion in the hip joints, with some contribution from flexion in the lumbar vertebrae. The foam/rubber buttocks were removed and instead low-density polyurethane foam was used to mimic flaccid tissue (Figure 1B). In both HTD test cases, the abdomen was removed to reduce trunk resistance. This was shown to provide more realistic motion in a Hybrid II test dummy (4).

*HTD Validation:* A single wheelchair user with T8 paraplegia due to traumatic spinal cord injury served to validate the modifications. The test dummies were clothed to provide similar

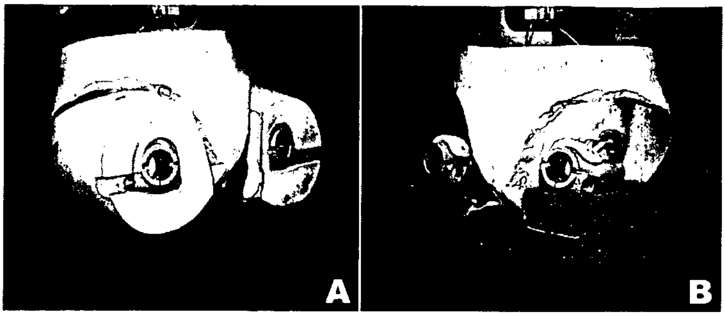


Figure 1A – "pedestrian" pelvis with trimmed thighs. Figure 1B –modified pelvis with buttocks removed and polyfoam to mimic flaccid tissue.

friction with the seat as the test pilot. A kinematic analysis of the trunk bending during a braking trial was used to endorse the modifications to the HTD. Active markers, infrared-emitting diodes (IREDs), were fixed to the shoulder, hip, and knee to capture the trunk motion (see Figure 2). The HTD and test pilot were seated in the wheelchair as depicted in figure 2 with arms abducted and forearm flexed to prevent using them for support during trials. While the test pilot was seated in the chair, two spotters were positioned approximately 1.5 meters beyond the braking line to intervene in case of falls.

*Test Wheelchair:* Validation was performed using one power wheelchair as the input: a Quickie P100 (Sunrise Medical, Inc.). The P100 was selected based upon availability at our research center and because it presented minimal risk of causing a fall to the test pilot. The HTD was seated on a 50mm polyurethane foam cushion while the test pilot sat on his own cushion, a Verilite Solo. IREDs were placed on the front edge of the seat pan and at the intersection of the seat pan and back support for determining wheelchair velocity, acceleration, and orientation.

*Experimental Protocol:* Testing was performed in the biomechanics test laboratory of the Human Engineering Research Laboratories. An OPTO*TRAK* 3020 (Northern Digital, Inc.) motion measurement system was used to sample 3-D position data of the IREDs at 240 Hz. Data were analyzed using custom programs written in Matlab (The Mathworks, Inc.).

Figure 2 – Experimental setup showing test pilot, test wheelchair, and OPTO*TRAK* system.

This pilot study was designed to maximize similarities between the test pilot and test dummies. A previous study by the author (4) determined that the strongest differences in motion between the test pilot and a Hybrid II test dummy occurred at lower decelerations such as braking the wheelchair by means of releasing the joystick. Using the power switch to stop the wheelchair (emergency power off braking) imparts higher forces on the occupant due to larger decelerations and consequently was used as the means of braking in this study. One test operator drove the wheelchair from the right side without obscuring the markers. A 6 meter run-up area was used to achieve maximum speed of the wheelchair. The test operator initiated the braking scenario when the front caster crossed a braking line labeled on the floor. Velocity and acceleration curves of the wheelchair were analyzed to pinpoint the exact start of braking.

*Data Reduction:* The trunk angular displacement was calculated using a sagittal plane projection of the knee, hip, and shoulder markers. Data were numerically differentiated to obtain trunk angular velocity, and acceleration. The trunk kinematics were used as measures of comparison between the test pilot and HTD. In addition, the speed of the wheelchair when braking was initiated was calculated to ensure a consistent input to the wheelchair/rider system. Ten repeated trials for each test case were compared using an analysis of variance (ANOVA). A significance level of $\alpha$=.05 was set *apriori*. A Tukey post hoc analysis was used when ANOVA revealed the existence of significant differences.

## RESULTS

No statistical differences were found in the wheelchair speed when braking was initiated, regardless of the rider. Statistical differences were present in the trunk angular displacement and trunk angular velocity between all test cases (p<.001 all instances). No significant differences were revealed in the trunk angular acceleration.

| | SB (m/sec) | | TAD (°) | | TAV (°/sec) | | TAA (°/sec²) | |
|---|---|---|---|---|---|---|---|---|
| **HTDs** | **1.88** | **(.02)** | **5.9** | **(.9)** | **38.5** | **(4.0)** | **690** | **(110)** |
| **HTDm** | **1.87** | **(.02)** | **53.4** | **(1.1)** | **124.7** | **(5.7)** | **811** | **(124)** |
| **TP** | **1.88** | **(.01)** | **75.4** | **(2.9)** | **198.5** | **(12.3)** | **788** | **(120)** |

Table 1. – The means ± (SD) of the wheelchair speed at brake initiation (SB), trunk angular displacement (TAD), velocity (TAV), and acceleration (TAA) are compared between the Hybrid III with standard hips (HTDs), modified hips (HTDm), and test pilot (TP).

## DISCUSSION

The trunk angular displacement, velocity, and acceleration are measures of the trunk stability of the test cases. Although significant differences in angular displacement and velocity were very strong (p<<.001) between the test pilot and both HTDs, the mean difference was much greater between the standard HTD and test pilot (69.5° & 160°/s) versus the modified HTD and test pilot (22° & 73.8°/s). Comparison between the HTD before and after alterations shows over an 800% increase in trunk motion. This is evidence that the simple modifications had a positive influence in achieving similar trunk stability and achieves this through bio-mechanically based flexion at the hips. Further modification to the hip assembly is likely unnecessary. Future work should focus on redesigning the lumbar spine. The lumbar spine was left unmodified in this study. A more flexible spine such as that of the Hybrid II, or a custom design of a low-density rubber elastomer would contribute to the overall flexion of the trunk. In addition, differences in anthropometrics, such as the mass and center of gravity location of the thorax, may account for some differences present between the modified HTD and test pilot. The modified hip/buttocks presented in this study is only a crude, rudimentary mock-up. The next step is to custom mold and shape polyurethane foam around the hips to allow for a more robust, test worthy dummy.

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# EFFECT OF ADULT-ONSET DIABETES AND/OR PERIPHERAL NEUROPATHY ON ACCELERATION THRESHOLD DETECTION DURING HORIZONTAL TRANSLATIONS

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## ABSTRACT

Slips and falls, and even the fear of falling can represent a major medical and functional deterrent to living independently, especially among the elderly population with adult-onset diabetes. The incidence of peripheral neuropathy in these individuals increases with age. In this study, we determined during short horizontal translations, the psychophysical acceleration threshold of 7 individuals (>50 yrs old) with diabetes and/or other peripheral neuropathy (PN), and 7 age-matched neurologically intact individuals. The acceleration detection threshold was significantly higher ($p<0.001$) in the neuropathic group; as was a trend towards increased quiet standing average anterior-posterior sway (AP) length and range.

## BACKGROUND

Nearly 16 million Americans (5.9 percent) have diabetes with another 5.5 million having undiagnosed adult onset diabetes, and with 0.8 million new cases diagnosed each year (data from Centers for Disease Control and Prevention). A prevalent side effect of diabetes is peripheral neuropathy, which is the damage or impairment of sensory or motor axons in the peripheral nervous system that results in a slowing of the conduction speed of signals in the nerves. Sixty to 70 percent of people with diabetes have mild to severe forms of peripheral nerve damage. It is believed that persons with peripheral neuropathy may have an increased incidence of slips or falls due to decreased somatic sensation [1].

Balance and fall initiation testing can range from the simple Romberg test, to completely instrumented tests. Extensive research exists on posture and balance during quiet standing in elderly and neuropathic populations [2,3], but the effect of diabetes *per se* has been assessed to a much lesser extent. Balance assessment primarily uses static or quiet standing tests, but instrumented tests have also been carried out with devices that make long and fast horizontal and/or rotational movements of the standing surface. The question of detecting the beginning of a potential fall in reality should be directed at the thresholds at which a change in balance control is sensed. However, the ability to detect threshold levels of perturbation during quiet stance has not been widely studied.

Robinson, et al, had developed a novel force platform system [sliding linear investigative platform for analyzing lower limb stability (SLIP-FALLS)], which rides on air-bearings and is controlled through a programmable multi-axis motion controller (PMAC) [4]. Faulkner, et al, had demonstrated the ability of the SLIP-FALLS system to perform acceleration and velocity threshold detection using adaptive psychophysical techniques in healthy young adult population (age<35) [5].

## RESEARCH QUESTION

Our objective was to evaluate the effect of adult-onset diabetes and/or peripheral neuropathy on the ability to detect sudden, but subtle displacements during quiet stance. Peripheral neuropathy presents not only a slower speed of both the afferent sensory information from the extremity and of the efferent muscle (motor) activation to the extremity, but also a dropout of afferent sensory and efferent motor channels. Thus, given the requirement in fall prevention for fidelity, speed and robustness, one might expect some correlation between the extent of peripheral neuropathy and the detection threshold or incidence of falls, even if compensatory strategies were in use. To test this hypothesis, an adaptive psychophysical threshold detection technique was used to determine the threshold level of acceleration that could be detected in those with diabetes and in age-matched adults (age>50).

## METHODS

Seven neurologically intact individuals (mean age 60 years; range 52–64 years; 2 females) and 7 with adult onset diabetes and/or other peripheral neuropathy (mean age 59 years; range 50–7 years; 2 females) were studied. A detailed screening of the patient's medical history (cardiac, neurological, and orthopaedic) was performed. Vision, reflexes, joint acuity, and tactile sensation (on the foot sole) were tested. A Mini-Mental Status Test evaluated cognitive mental state. Anthropometrical measures were recorded. Peroneal and tibial motor, and sural sensory nerve conduction tests were carried out with Nicolet Viking IV, with institutional standards determining the extent of neuropathy. As part of our threshold test protocol, subjects stepped barefooted on the force platform (which had been kept warm by a heating blanket) and positioned their feet in a side-by-side stance in a designated area. Tri-electrode EMG electrodes were used bilaterally to monitor gastrocnemius/soleus and tibialis anterior muscle activity. Subjects wore a blindfold to eliminate visual cues; and headphones to mask with white noise any unwanted auditory cues, and to provide instructional commands. Subjects took 10 two-alternative-forced-choice (2AFC) practice trials at super-threshold acceleration values (feedback provided), for each displacement before threshold determination was performed at that displacement.

Acceleration thresholds for three perturbation lengths (1, 4 and 16 mm) were determined using the 2AFC protocol (PEST criteria). Subjects were given four voice commands, "READY", "ONE", "TWO", and "DECIDE" via the headphones. A perturbation occurred after either the word "ONE" or "TWO." Subjects pressed a wireless doorbell button one or two times after the cue "DECIDE" to indicate that they perceived the perturbation in the ONE or TWO interval, respectively.

To compensate for potential fatigue factors, a modified PEST methodology was used. The modifications were: 1) replacing the Wald constant calculation with the Staircase-71 for first 10 trials, and Staircase-79 from eleventh trial till threshold determination for deciding when to change the stimulus level, and 2) limiting the maximum number of trials to 30 per displacement. When threshold was not reached within 30 trials, a threshold level was chosen by determining when a stimulus level was detected at least 80% of the time. Validity of the threshold for a displacement was tested in separate sequence of 10 trials at threshold and at 125% threshold, where reaction times to the perturbation were determined. Reaction times to foot-sole touch and to an auditory tone were also tested. Center of pressure (COP) measures were computed from the four calibrated load cells supporting the force platform. AP sway was determined after filtering COP with a pass band of 0.5 to 5 Hz.

## RESULTS

None of the subjects had any neurological, orthopaedic or cardiac condition, other than diabetes or peripheral neuropathy, which would affect their ability to detect a threshold level perturbation. The mini-mental status mean score was 28.9 (SD 1.5), with no significant difference between the groups. Thus, all the subjects were cognizant and could follow instructions given to them. All diabetic subjects had incidence of peripheral neuropathy (motor and/or sensory), while the age-matched group had none.

**Figure 1. Acceleration Threshold in Elderly**

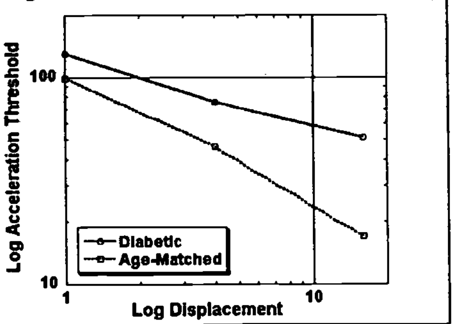


**Table 1: Quiet Standing AP Sway (eyes closed)**

| | RMS (mm) | Range (mm) |
|---|---|---|
| **Diabetic / PN** | 4.28 ± 1.69 | 18.70 ± 7.39 |
| **Age-Matched** | 3.01 ± 1.09 | 13.01 ± 4.85 |

Subjects with diabetes/peripheral neuropathy had significantly higher acceleration detection thresholds than those without ($p<0.001$), at all displacement levels [Figure 1], and higher (not significantly different) quiet standing, eyes-closed, AP sway [Table 1].

## DISCUSSION

In the population we tested, those with diabetes had some extent of peripheral neuropathy. This finding is in agreement with the popular perception of a high incidence of peripheral neuropathy in the diabetic population. With the high incidence rate of adult onset diabetes (800,000), there needs to be a higher awareness in fall prevention and creating environments where fall can be prevented. The acceleration detection threshold in the diabetic population is higher than age matched cohorts.

At low displacement (1 mm) the difference in the acceleration required for detection of movement is lower but still significantly higher ($p<0.01$) than their age-matched cohorts. For a longer displacement, the acceleration threshold is much higher ($p<0.0001$) in subjects with diabetes. This implies that the populations with peripheral neuropathy have extreme difficulty in detecting a slip or fall initiation, which could be of low acceleration but long translation.

This condition is typical of stepping on top of a patch of ice or a banana peel or walking on a wet floor. This puts the diabetic population at a greater risk for fall. Individuals with diabetes should be made aware of this predisposition and educated with fall-prevention and fall-breaking techniques when encountering such environments. AP sway in diabetic population was observed to be higher than their age-matched cohorts, but getting a significant difference may require a larger population.

Presently analyses are being performed to better understand the implication of the higher acceleration threshold. Further work in this area should investigate the effect of other peripheral neuropathies on the acceleration threshold and differences from diabetes-induced peripheral neuropathy.

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