XVI. Wheelchairs and Powered Vehicles

A. General

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XVI. Wheelchairs and Powered Vehicles

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A. General

[568] Adaptation of Wheelchair Standards for VA Policy and Purchasing Requirements

Robert W. Hussey, MD; Lynn Phillips Bryant
Hunter Holmes McGuire VA Medical Center, Richmond, VA 23249; Wheelchair Standards Committee, C/O RESNA, Washington, DC 20036

Sponsor: VA Rehabilitation Research and Development Service (Project #B228-2RA)

Purpose—The purpose of this project is to complete the development of standards for wheelchairs; design a pilot database for collection and use of wheelchair standards testing data; and develop guidelines for use of the standards by clinicians.

Progress—All 17 parts of the standards have been completed and have been submitted to the American National Standards Institute (ANSI) for approval. Standards submitted to ANSI generally are approved within 3 to 6 months of submission; it is expected that ANSI-approved standards will be available no later than March 1991.

The pilot database has been completed and is ready for beta testing. It was developed by RehabTech Associates of Ellicott City, MD in accordance with the Department of Veterans Affairs (DVA) and the Association for the Advancement of Rehabilitation Technology (RESNA) specifications.

The clinical guidelines are in the process of final revision and will be submitted to DVA for review.

Methodology—The wheelchair standards have been developed over a 10-year period by a committee of rehabilitation engineers, clinicians, wheelchair manufacturers, distributors, wheelchair users, and federal agency (DVA and FDA) representatives. The United States (US) committee has coordinated its standards development efforts with those of the International Standards Organization (ISO) so that wheelchairs produced the world over are held essentially to the same standards. This will make it easier for US users and dealers to import wheelchairs for their use and for US wheelchair manufacturers to export wheelchairs for sale in other countries.

The database was developed in response to needs and requests outlined by the DVA and the Wheelchair Standards Committee. It includes test data disclosure formats for individual wheelchairs, as well as the capability of comparing the performance of two or more wheelchairs on any given test, and the capability of compiling data for all wheelchairs tested.

The clinical guidelines were developed based upon the recommendations and suggestions of DVA clinicians. The guidelines also utilize additional input from the US and ISO committees.

Results—Once the standards have received final ANSI approval, they will be reviewed on a yearly basis by the US committee, and changes/modifications may be made to these standards based upon that review. Copies of the standards are available through RESNA (the official standards development organization of record) and through ANSI.

Information about the availability of the database program, comparative data, and clinical guidelines also can be obtained from RESNA.

Recent Publications Resulting from This Research
Purpose—Eleven participants with an average age of 67 tested 19 different wheelchairs provided by manufacturers.

Methodology—Users were asked to open and fold, get into and out of, operate all components (wheel locks, footrests, etc.), and lift each wheelchair. Each subject was timed and asked his/her opinion about the “ease” of completing each task, as well as their “sense of stability” when entering and exiting the chair.

Later, each appliance was put through its paces on an obstacle course. Participants maneuvered these chairs on a 25-foot hard wooden floor, carpeting, a gravel surface, and a 20-foot ramp. Every task was timed, the number of strokes counted, and participants queried about the performance of each chair. The distance covered with one stroke of the wheel was also measured.

Results—Our subjects found the standard chair compared favorably with lightweight and ultralight chairs on hard flooring, but not on carpeted or gravel surfaces. Standard chairs took less time to open/fold, but the additional weight of these chairs slows them down. Standard chairs consistently took more time to complete their trials and didn’t travel as far with one stroke.

Lightweight chairs performed better in rollability than standard chairs, but came in second to ultralights. They took longer to open and fold than the other chairs.

Lightweights performed best of all in climbing a ramp, similar to a “curb cut,” or that portion of sidewalks cut away for wheelchairs at street crossings. The reasons for this could be twofold. First, compared to a standard chair, the lightweight goes further with a single stroke. Second, for the inexperienced, an ultralight chair tends to buck or raise up when the wheel is pushed hard, such as going up a slope. Antitipping devices prevent it from going over, but using an ultralight requires practice. Although our testers practiced with each chair before each trial, none of them had used anything but standard chairs before this test.

Ultralight chairs, which often have fewer structural components, appear to provide less support, but our evaluators felt they were no less stable than standard chairs. Sixty-five percent of the participants could lift an ultralight chair 16 inches, when only 25 percent could lift their own (standard) chairs.

Ultralights performed best in crossing carpeted and gravel surfaces and rolled further than the other two chairs on all three surfaces (hard flooring, carpeting, and gravel surface). Participants had difficulty manipulating the front rigging, but found the wheel locks on the inflatable tires easier to apply than on the other chairs.

Many users have never been properly fitted. The personal chair of every evaluator was reviewed before testing began, and only one out of the 11 was fitted according to standard sizing guidelines. The chairs were too wide, too high, or too low. In one instance, the variance was more than five inches. At best, an ill-fitting chair is uncomfortable. At worst, it causes bruises, poor posture, pressure sores, and limits mobility.

Recent Publications Resulting from This Research
The cost of enforcing this avoidance of deep discharge is also being evaluated, considering user convenience, technology required, and safety.

The objective is to maximize battery life and minimize inconvenience and complexity of control of electric wheelchairs.

Methodology—Three groups of wheelchair users were identified: 1) “bad” users who constantly fail to achieve 6-months’ life from battery sets; 2) “normal” users with a variety of electric wheelchairs; and, 3) “normal” users who have low-voltage cutoff devices fitted to their wheelchairs. Fifty percent of Group 1 had low-voltage cutoff controls fitted, 50% remain unaltered.

All groups were fitted with new batteries and capacity checks and replacement records were kept. Any significant changes in the users’ lifestyles were also noted (e.g., sporting interests, change from school to employment).

Progress—Testing is continuing, since many of the subjects are still on their original set of batteries. However, indications are that it is cost-effective to limit the degree of discharge. After the familiarization period, no complaints have been received concerning the reduced distance covered per battery charge, and all participants are successfully avoiding the deep discharge cutoff point during their daily use of wheelchairs.

Results—The initial group sizes were as follows: 1) 10 participants; 2) 20 participants; and, 3) 20 participants.

Group 1 had an increase of 34% in battery life when fitted with voltage limiting controllers; Group 1 with existing controllers had an increase of 8% in battery life; Group 2 had a 2.4% increase in battery life; and, Group 3 had a 9% increase in battery life.

Implications—The inferences that can be drawn at this stage are that there is a general increase in usable life of battery sets due to improved regulation of chargers and the availability of larger ampere hour capacity batteries more suited to the daily demands of our young clientele. The second inference is, from the results of Group 1, that the provision of low-voltage cutoff facilities in a wheelchair controller contributes significantly to the life of a battery set. The researchers feel it is too early to come to clear conclusions, as many of the users are still on their first battery set, and the effect of a winter season on wheelchair batteries has yet to be accounted for.

Future Plans—The testing will continue until all users have exhausted at least one battery set, and a full year’s cycle has been completed. The advent of microprocessor-controlled wheelchair controllers, with a programmable low-voltage cutoff facility, will enable us to investigate the effect of different levels of voltage cutoff on battery life, and thus, operating costs.

[571] International Wheelchair Standards: A Study of Costs and Benefits

Mark Hartridge, MIE Aust; Barry R. Seeger, PhD
Rehabilitation Engineering Division, Regency Park Centre for Young Disabled, Kilkenny, SA 5009 Australia

Sponsor: Channel 7 Children’s Medical Research Foundation of S. Australia

Purpose—The purpose of this study was to compare the total purchase and ownership costs of electric wheelchairs meeting International Standards requirements, with apparently cheaper wheelchairs that do not meet these standards.

Methodology—Models of wheelchairs that complied with requirements based on ISO 7176 were identified and samples were subjected to laboratory tests simulating one year’s active use. Accurate account was kept of failures, repair costs (labor and parts), and downtime.

Wheelchairs that did not comply with the requirements based on ISO 7176 were then subjected to identical testing and the two sets of costs compared.

Progress—Eight parts of ISO 7176 have now been published, also six parts of the Australian Standard AS 3696, which set out testing methods and procedures. Publication date for the full Australian Standard, Wheelchairs, Product Requirements, is scheduled for this year.

Testing of two brands of standards quality and non-standards quality powered wheelchairs has been completed.

Calculations have been made of running costs, repair costs, and costs of upgrading current production wheelchairs to standards quality. These calculations included allowance for design time, testing costs, updating of drawings and manuals, and disposal of obsolete parts. They did not include costs of reduced warranty claims or
Wheelchairs and Powered Vehicles

indirect expenses incurred by wheelchair breakdowns (e.g., alternative transportation and rescue operations). The upgrading process is within the capacity of most manufacturers.

Results/Implications—The study indicated most clearly that standards-quality electric wheelchairs are good economic propositions, the extra initial cost being recouped well within the first year of use.

Benefits of using a standards-quality wheelchair in our tests included an increase in mean distance between failures (MDBF) from 261 to 6,000 kilometers, a 68% decrease in the total number of faults (ISO Class 1, 2, and 3), and a reduction of 92% in repair time for the standards-quality wheelchairs.

The testing laboratory has now received full National Association of Testing Authorities accreditation for wheelchair and rehabilitation equipment mechanical testing.

Recent Publications Resulting from This Research

[572] Toward Further Development of a Modular Wheelchair Tray for the Physically Disabled

Stephen Naumann, PhD, PEng; Penny Parnes, BSc, DSPA, Reg OSHA; Susie Blackstein-Adler, BScOT;
Steve Ryan, BESc, PEng; George McMillan; Louie Scalabrelli
The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario M4G 1R8 Canada

Sponsor: National Health Research and Development Programme, Department of Health and Welfare, Canada

Purpose—Our purpose is to develop a modular wheelchair tray which meets the therapeutic and communication goals of the clinician and the personal needs of the user and caregiver.

The specific goals are to: 1) develop an upgraded modular wheelchair tray which can be partially tilted to various positions and folded away beside the wheelchair by the caregiver; and, 2) fabricate and assess the performance of the upgraded modular tray.

Progress—Development of a second-generation modular system has focused on creating hygienic, lightweight tray modules which can be customized to accommodate a client’s seating insert, as well as the user’s communication device and wheelchair control interface when appropriate.

The prototype tray system incorporates a hinged, adjustable distal section, a laminate construction consisting of thin, molded Kydex, and a stiff polycarbonate honeycomb core. To cushion the tray and protect any delicate communication device nested in the tray from inadvertent collisions, an integral lip reinforced with high density polyethylene is provided. The proximal section is also a laminate but does not have a raised lip at its periphery. This ensures that the folded thickness of the tray is minimized. Hardware attached to the proximal tray and the wheelchair permits the tray to be folded and stored beside the chair without requiring its removal.

Methodology—Seven subjects, 5 to 29 years of age, participated in the clinical field trials which were of no less than 6-weeks’ duration.

Results—Results of the evaluations by caregivers suggest that the prototype tray system was well received. The system was found to be durable and safe to use, and the tilt feature appeared to facilitate user access to communication systems. The fold-away option was also found to be useful.

With the provision of a variety of distal tray modules, the production version of the tray is expected to offer a functional arrangement that will closely conform to the needs of most physically disabled persons requiring an augmentative communication system.
[573] Ergonomics of Manual Wheelchair Propulsion

L.H.V. van der Woude; H.E.J. Veeger; R.H. Rozendal
Faculty of Human Movement Sciences, Free University, Amsterdam, The Netherlands

Sponsor: Innovative Research Programme for the Disabled

Purpose—Manual wheelchair propulsion was studied from a combined physiological and biomechanical perspective, with the general aim of improving the mobility of wheelchair users. A better understanding of factors influencing the work capacity and power output of the wheelchair user, and those factors influencing the wheelchair-user interaction, is fundamental in this respect.

Methodology—Wheelchair propulsion was studied by placing a wheelchair on a motor-driven treadmill and simulating conditions on a computer-controlled wheelchair ergometer. A complete three-dimensional (3-D) reconstruction of the movement pattern was combined with measures of force and power production and electromyography of upper arm and trunk muscles. An inverse dynamic segment model was used to interpret cardiorespiratory phenomena and measures of efficiency from a biomechanical and anatomical perspective.

Progress—Studies have begun on the effectiveness of torque production under various conditions of power output and in different groups of disabled and nondisabled subjects.

Recent Publications Resulting from This Research

[574] Functional Assessment of the Performance Capacity of the Wheelchair-User Combination in the Course of Rehabilitation

L.H.V. van der Woude; P.J. Meijs; R.H. Rozendal; M.T. Soede; R. Veenbaas; C.J. Snijders
Faculty of Human Movement Sciences, Free University, Amsterdam, The Netherlands; Institute for Rehabilitation Research, Hoensbroek, The Netherlands; Department of Biomedical Physics and Technology, Erasmus University, Rotterdam, The Netherlands

Sponsor: Innovative Research Programme for the Disabled

Purpose—A protocol will be designed and tested for the functional evaluation of the wheelchair-user combination during the course of rehabilitation. Spinal cord injured subjects will be evaluated repeatedly with the help of this protocol. The predictive value of the protocol with respect to the functional capacity of the future wheelchair user and the wheelchair will be evaluated. Thus, the selection and provision of a given type of wheelchair, at a given stage of rehabilitation, may be determined more accurately.

Methodology—Exercise tests will be performed on a stationary transportable wheelchair ergometer and on a standardized wheelchair track. Heart rate and ECG will be monitored in conjunction with power output and energy cost. Both a sprint protocol and an aerobic maximum exercise test will be conducted on the ergometer at different stages in the rehabilitation process. The cardiorespiratory stress of several tasks on the wheelchair track will be evaluated similarly.

Progress—Exercise protocols are being tested. The wheelchair track is currently being designed and the stationary wheelchair ergometer is being built. Preliminary data from recent tests (both sprint and max) on a group of 44 male spinal cord injured subjects who completed the rehabilitation program several years before are currently being processed.
Wheelchair Evaluation

Micheal D. O’Riain, PhD, PEng; Andrew Phillips, BASc; Gilbert Layeux, Reg Tech; Harold Gay, Reg Tech
Department of Rehabilitation Engineering, The Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada
Sponsor: Ministry of Health of Ontario; Royal Ottawa Health Care Group

Purpose—The purpose of this project was to develop equipment and procedures to test wheelchairs prior to their being funded by the Assistive Devices Branch of the Ministry of Health of Ontario. Test procedures have been set up and criteria for acceptance or rejection of new wheelchairs are being established.

Progress/Results—The facilities for testing wheelchairs have been refined and a parallel testing facility has been set up at Victoria Hospital in London, Ontario. The results obtained in the two centers are compared regularly to ensure that both testing facilities and procedures are operating correctly.

All of our results are being placed on a database which, when added to other data available from organizations such as the International Standards Organization, the Department of Veterans Affairs, the British Standards Institution, etc., will allow us to determine what is acceptable and what is not. A list of necessary criteria for acceptance is being prepared for the manufacturers so that they know what is expected of their products before presenting them for evaluation.

Rehabilitation Engineering Center for Personal Licensed Transportation for Disabled Persons

John G. Thacker, PhD
University of Virginia, Charlottesville, VA 22901
Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The Rehabilitation Engineering Center for Personal Licensed Transportation for Disabled Drivers was established July 1, 1990 by the National Institute on Disability and Rehabilitation Research. The ability to move from place to place rapidly, conveniently, safely, and economically is a prerequisite to full participation in any society. Although both private and public transportation systems exist, private transportation in a personal vehicle is frequently the only means of transportation available for the handicapped person. There are, however, no commonly accepted standards for the adaptation of personal vehicles to accommodate disabled individuals as drivers or passengers. Adaptations may compromise the structural stability and safety of the vehicle, may not provide easy boarding or safe and rapid exit from the vehicle, and may include unsafe or ineffective control devices. Seating systems and systems for securing wheelchairs in the vehicles are often unsafe and ineffective.

The objectives of this Center are to elevate the state-of-the-art technology and knowledge relevant to personal transportation systems to the highest possible level, and to transfer this knowledge and technology to a level of practice that results in optimum utilization. In order to accomplish these objectives, 14 tasks have been defined within the Center. They are: 1) identify and catalog vehicle safety access and exit systems; 2) assess deficiencies in assistive technology for personal transportation systems; 3) develop methodologies for checking device compliance with existing federal or state standards; 4) develop methodologies for evaluating equipment to be used when assessing individuals’ needs for vehicle modifications; 5) develop methodologies to evaluate vehicle access and exit systems for safety and effectiveness; 6) develop and validate methodologies to evaluate and improve the effectiveness of wheelchair tie-downs and occupant restraint systems, and the safety of vehicle structure; 7) develop methodologies for performing structural integrity analysis of vehicle modifications for disabled persons; 8) develop an analytical methodology for evaluating and improving wheelchair tie-downs and occupant restraints; 9) develop protocols for physical tests of vehicle structural modifications for safety; 10) develop protocols for the physical testing of wheelchair tie-downs and occupant restraints for crashworthiness; 11) develop a program for training in these areas; 12) develop a method for dissemination of this information; 13) conduct a state-of-the-art study of personal transportation systems to help direct and plan research...
and development activities of the Center; and, 14) to
develop improved designs for equipment, devices,
and modifications for personal vehicles for disabled
individuals.

Implications—The realization of these objectives and
tasks will result in optimum matching of vehicles, modifi-
cations, safety systems, and adaptive driving devices to
the needs of the individual disabled driver. The modifi-
cations made to the vehicle will not disrupt the continuity
of load-carrying structures; adaptive devices and safety
systems would be ergonomically designed for efficacy of
use according to individual requirements; the reliability
of modifications, tie-downs, occupant restraints, and
adaptive devices will exceed the useful life of vehicles in
which they are installed. Finally, the dissemination of
information to consumers, service providers, manufac-
turers, and third-party payers would insure that all dis-
abled individuals with a potential to benefit would have
access to the technology and services.

[577] Research on Improving Wheelchair Frame Durability

James J. Kauzlarich, PhD; John G. Thacker, PhD; J.D. Baldwin, MS
University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903
Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The intention of this work is to keep the stress
analysis of wheelchair frames at the personal computer
level to demonstrate to the designers and manufacturers
that high-cost large computing machines are not neces-
sary to perform these types of analyses.

Progress—The work during this last project period con-
stituted of developing finite element (FE) models for both
powered and manual wheelchair frames. Detailed FE
analyses have been performed on two wheelchair designs,
one a conventional cross-frame power model, and the other
a single-member side frame “spring” model. Both wheel-
chair models were developed to improve our understand-
ing of the way occupant loads are transferred to the frame
members and to establish the high stress regions in each
design. The PAL2 FE code from the MacNeal-Schwendler
Corporation was used to perform the calculations. PAL2
was run on an IBM PC-compatible personal computer.

The power wheelchair FE model consisted of 195
tubular elements and 1,046 active equations. The frame
was assumed to be constructed from UNS 10100 cold-
drawn steel tubes with nominal wall thicknesses of 0.060
inches. The occupant was assumed to weigh 180 pounds
and the frame was loaded according to static measure-
ments made at the University of Virginia Rehabilitation
Engineering Center (UVA-REC). A maximum von Mises
stress of 22,470 pounds per square inch was calculated at
the midpoint of either 1.014-inch OD cross brace tube.
This particular model was used in conjunction with the
work accomplished in the reliability studies.

The spring wheelchair model consisted of a frame
tube that was assumed to be constructed from SAE 4130
steel tube with a nominal outside diameter of 1 inch, and
a wall thickness of 0.058 inches. The model was com-
posed of 528 quadrilateral plate elements and has 2,600
active degrees-of-freedom after constraint. The single-
tube sideframe was modeled carrying half of the assumed
180-pound occupant weight.

Preliminary Results/Future Plans—Two analyses of
this structural member were performed. In the first, the
90-pound occupant load was applied equally along the
top section of the tube where the seat would rest. It was
determined that the maximum von Mises stresses occur
at the inside of the 3.5-inch radius bend and have a value
of 44,380 pounds per square inch (compression). The
tensile stress at the outside of the tube are of similar
magnitude. The second analysis determined that the tube
structure has a spring constant in the plane of the tube of
about 106 pounds per inch. A 90-pound concentrated
load applied at the free end produced a vertical deflection
of the free end of 0.85 inches.

Because of the model size limitations imposed by
PAL2 on dynamic calculations, no dynamic analyses
were performed on these two wheelchair models. PAL2
allows only 100 active degrees-of-freedom for
dynamic analysis, which is insufficient to model a
cross-brace wheelchair structure. We are now seeking
other PC-based FE models to accurately model wheel-
chair frames.
Purpose—Electrically-induced exercise of paralyzed or paretic muscle is known to be clinically beneficial, and under experimental conditions, even functional. However, benefits accrue and are maintained only with frequent and habitual exercise. Few persons who are clinically eligible (e.g., whose muscles and final common pathways are intact) for electrically-induced exercise actually receive it for lack of safe, simple, and affordable means. Many of these persons currently use wheelchairs as their primary means of transport; these, however, do nothing to curb further atrophy and may even exacerbate pressure sores, edema, and contractures in lower limbs that are more or less fixed in pendant position. Our purpose, then, is to develop a wheelchair that maintains all standard functions, but also provides a means of frequently and habitually exercising, via electrical stimulation, paralyzed or paretic limbs while the user is engaged in normal daily activities. The exercise is designed to be functional in that it augments propulsion of the wheelchair, although at no time is movement of the wheelchair dependent on that activity.

Methodology—Hand cranks on folding, adjustable towers are bolted to sport model wheelchair frames just in front and to the side of the leading edge of the seat. Hand cranks are lined to reciprocating footglides and rear wheels via belts. Turning both hand cranks forward simultaneously results in movement of the footglides and forward rotation of the rear wheels of the wheelchair. Turning the hand cranks backward disengages the footglides (via a clutch), but drives the rear wheels in reverse. Steering is accomplished by differential use of the hand cranks. A computer senses the position of each footglide, and if a variety of requirements are met (e.g., going forward, within certain speeds, etc.) turns on and off at appropriate times, individual channels of commercially available neuromuscular stimulators. These in turn stimulate muscles that drive the footplates back and forth. Force produced by the stimulated limbs thereby augments propulsion of the wheelchair. Speed and direction are always under voluntary control of the user; only timing of stimulation is computer-controlled.

Progress—A functioning prototype has evolved from several designs. Mechanical aspects of the prototype have been field-tested and revisions made; electronics are still being bench-tested.

Results—Our prototype maintains all functions of a standard wheelchair (e.g., it folds, fits under a standard desk or table, can be pushed or propelled in the usual fashion), yet can convert to crank mode or from crank mode to standard mode in less than 5 seconds. Steering and braking are simple and effective. Because power is delivered to the rear wheels through 360 degrees of crank rotation, propulsion is far more efficient than standard means, and average cruising speed increased. The wheelchair can be operated in the normal way even when cranks are erected. Although the wheelchair can be pulled into and maintained in "wheelie" position, weight is unacceptably high. The electronics function properly, but need customizing to reduce size and weight.

Future Plans—All components will be brought to commercial grade and the system thoroughly tested for safety and efficacy in clinical and field conditions.

Recent Publications Resulting from This Research

Patents
An Italian Consumer Survey of Wheelchairs

R. Ronchi; C. Huriet; R. Martinucci; I. Johnson; A. Santagostini; A. Pedotti
Servizio Informazioni Valutazione Ausili, Milano, 66-20148 Italy
Sponsor: The Region of Lombardy

Purpose—The purpose of this project was to investigate wheelchair use among a large number of consumers, and to integrate the method into the general Servizio Informazioni Valutazione Ausili (SIVA) wheelchair evaluation program.

Methodology—In 1986, an experimental questionnaire was designed and distributed to approximately 100 persons. This experience proved positive, and in 1987 an improved version was distributed. Ten thousand copies were sent all over Italy for a complete consumer survey. Magazines, rehabilitation centers, and associations of disabled persons were involved. During a period of 2 years, about 1,000 questionnaires were returned to SIVA; 731 of them were valid for processing. Special software was designed to process the results. The questionnaires were read and interpreted easily, because preselected answers were used, needing only a confirmation mark. The survey included 45 questions concerning personal data about the consumer, model and type of wheelchair, where and when the wheelchair was used, the consumer’s evaluation on various aspects (e.g., mobility, brakes, transfers, maintenance), and general opinions about design and safety.

Results—The survey covered manual and powered wheelchairs for adults, purchased between 1976 and 1987. Twenty-nine trademarks were represented, 11 of them belonging to foreign companies. The data profiled fairly active wheelchair users, mostly with neurological or muscular diseases, who use their wheelchairs for all purposes. Previous experiences in other wheelchairs were reported so that users were able to compare their wheelchair to other models. In the majority of cases (71%), the wheelchair was prescribed and user cost was reimbursed by the National Health Care system or the insurance company. Fifty percent of the users did not have the opportunity to try the wheelchair before delivery, and 42% said the selection of the model was made by someone else. Breakdowns were shown in 76% of the cases, and one-third of these users reported difficulties in having the wheelchair repaired. Still, 68% of the users concluded that they were satisfied with the wheelchair choice.

Future Plans—This experience, the first in Italy, is the basis for SIVA, and for further research and development of the technical and functional evaluation of wheelchairs. The results support using standardized tests for additional information concerning wheelchair use in the field.

Recent Publications Resulting from This Research

Investigations into the Influence of Wheel Position on the Propulsion Capabilities of Wheelchair Users

G. Bardsley, PhD; A. Rose, BSc
Tayside Rehabilitation Engineering Services, Dundee Limb Fitting Centre, Broughty Ferry, Dundee DD5 1AG, UK
Sponsor: Tayside Health Board

Purpose—Many wheelchair users have only marginal ability to independently propel their wheelchair. Their ability can be enhanced by optimizing the position of the wheelchair wheels. Many wheelchair designs provide the necessary adjustability, but difficulties can be experienced in determining the optimum setting for individuals.

Progress/Methodology—A highly adjustable wheelchair has been developed to simulate the dynamic characteristics of wheelchairs while permitting ready adjustment of the wheel positions. A series of standardized tests and maneuvers have been developed with simple measures of performance. Disabled subjects have conducted these tests for variations in the wheelchair simulator.
Results—The results of these preliminary studies have shown that the methodology can detect the influence on propelling performance of wheel position in both vertical and horizontal displacements. The results are generally in agreement with those of other studies using static dynamometers.

Future Plans—Further funding is being requested to expand this project to incorporate larger numbers of subjects. It is intended to determine more clearly the influence of wheel position and include other variables such as wheel diameter, handrim diameter, and castor configuration.

A simplified wheelchair simulator and test procedures are to be developed for use as routine clinical tools for optimizing wheelchair configurations for individual people.

[581] Comparative Evaluation of Chargers for Wheelchair Gel Cell Batteries

Rob E. Garrett, BTech; Mark Hartridge, MIE Aust; Barry R. Seeger, PhD
Rehabilitation Engineering Division, Regency Park Centre for Young Disabled, Kilkenny, SA 5009 Australia

Sponsor: None listed

Purpose—This study was undertaken as part of our ongoing work to upgrade wheelchair quality. Our purpose was to compare the commercial battery chargers available in Australia for Sonnenschein A200 24 Ah and 36 Ah gel cells in order to determine which of them would be the best value for our clients.

Methodology—Laboratory tests were conducted to determine which battery chargers would ensure that the users' batteries were fully charged each night, and also ensure that the battery lifetime was not diminished. Five commercial chargers were tested on a standardized pair of Sonnenschein gel cell batteries. We developed a battery charger test facility which enabled us to monitor the maximum case temperature during charging, energy from the batteries, efficiency of energy transfer, sensitivity to main voltage fluctuations, direct current, ripple current, peak charge voltage, and typical charging characteristics. We also compared purchase price, size, mass, whether the suitable battery type was clearly marked, safety factors (reverse polarity protection and short-circuit protection), indicator lights, and human factors.

Results—Results of this study have indicated a clear preference between chargers, although none of the chargers conforms to the battery manufacturer’s specifications.

Implications—As a result of this research, we have changed the chargers we purchase. We anticipate that our clients will now experience longer life from their wheelchair gel cell batteries. We have also identified a need for a 6 A DC-style battery charger to ensure that the charge time for 36 Ah batteries is of the order of 8 hours, corresponding to a full recharge overnight.

Another benefit of this research is that some manufacturers are now upgrading their products with the assistance of our testing laboratory.

Recent Publications Resulting from This Research
B. Powered Controllers

[582] Linear Synchronous Motors for Power Wheelchairs

Kent R. Davey, PhD; David A. Ross, MSEE; Lutz Kynast; Bobby Chung
Rehabilitation Research and Development Center, VA Medical Center (Atlanta), Decatur, GA 30033
Sponsor: VA Rehabilitation Research and Development Service (Project #B338-4RA)

Purpose—The purpose of this project is to develop a highly efficient direct drive axial flux motor for powered wheelchairs. The lightweight motor (about 23 lbs) will fit inside a 14 x 2 inch wheel with stall torque of 35 pound-feet and an average efficiency of about 80%. An additional goal is to minimize the “cogging” which causes motors of this type to “stick” in certain locations, thus increasing vibrations and losses in power.

Methodology—Based on current findings in motor research, a promising motor design idea was constructed. This design was coined a Linear Synchronous Motor (LSM). The prototype verified the workability of the initial design idea, given certain modifications in geometry and placement of magnetic materials. The design method was then chosen to be a combination of computer modeling and physical modeling of certain parts of the motor. The process was then repeated until the project goals were met.

A simple microprocessor-based controller was developed using a HP development system to run the prototypes. A refined controller will be developed in conjunction with the final prototype to meet the project goals.

Progress—Two prototypes have been constructed and tested in addition to the five prototypes constructed in the previous year. A microprocessor-based controller (based on the 6809 microprocessor) has been designed and implemented. A third prototype has been designed and is now being constructed.

A three-dimensional finite element modeling software package has been evaluated and ordered to be used for the computer modeling of the motor to give more precise predictions. An upgrade for the HP 9000 minicomputer has also been ordered to run the software.

Preliminary Results—The full testing of the first prototype of 1990 revealed one remaining problem in achieving our goals. The efficiency and torque were achieved but a considerable amount of cogging still remained. This led the engineers to design another prototype after a considerable amount of testing from a “jig” that simulated pieces of the motor. This prototype dramatically reduced the cogging while keeping the other goals attainable. The difference between this prototype and the first is in the orientation of magnets and teeth.

The second prototype was then modeled by computer to determine the optimum size of magnets and spacing of the air gap. Better magnetic materials were chosen for the design of the next prototype.

The third prototype is being constructed and should minimize the cogging torque.

Future Plans/Implications—A “low cost” version of the system will be constructed using inexpensive ceramic magnets and will be evaluated. Other versions will be designed and constructed to determine an optimum configuration for the limits of the system. The controller will be refined to include a digital signal processing chip which will provide intelligent control of efficiency and wheel motion.
Purpose—The Ultrasonic Head Control Interface (UHCI) is a device designed to provide severely disabled individuals (quadriplegics) with a means of controlling devices, such as electric wheelchairs, in a socially acceptable and aesthetically pleasing manner.

Progress/Methodology—In this project, two Polaroid ultrasonic distance ranging sensors are the basis for a new type of human-machine interface. They emit inaudible high-frequency sound waves which propagate through the air until reflected by an object. A portion of the signal incident on the object is reflected as a echo and is detected by an electronic system. The elapsed time from transmission of the signal to the reception of its echo is proportional to the round-trip distance from the sensor to the object. In this rehabilitation application, two separated sensors are directed at the head of the user. The two resultant distance ranges, one from each sensor to the head, and the fixed distance between the stationary sensors describe a triangle whose vertices are the two sensors and the current head position of the user. A geometric relationship allows the offset from the baseline and center-line of the two sensors to be calculated. The array of distance-ranging sensors can monitor the head position of a severely disabled quadriplegic operator to obtain command and control information for the operation of mobility, communication, and robotic devices.

In operation, the user of an UHCI merely tilts the head off the vertical axis in the forward/backward or left/right directions. The translation of head position information into electrical signals can mimic the output of a joystick. Both can be used to control devices to which they are attached, such as a wheelchair, a communication aid, a video game, or a robotic arm.

Preliminary Results—Within the VA Rehabilitation Research and Development Service (RR&D), UHCI have been installed on two electric wheelchairs. The first is an Everest & Jennings model 3P equipped with a reclining Recaro seat and is in use in France by a quadriplegic woman. The second, mounted on an Invacare Rolls IV with a Solo Products Power Pack, continues to be demonstrated at RR&D and evaluated by spinal cord injury patients at this VA facility.

Both units have been operational since June 1983. User evaluation has been performed with 10 quadriplegic individuals. After a short demonstration and training session, they were transferred into the chair and most were able to successfully navigate the chair without problem. Users stated that they preferred the ultrasonic head control to the chin-controlled joystick wheelchairs they had used. The device has proven to be easy to use. Its intuitive operation requires little focused concentration and thus does not result in user fatigue.

Funding for the construction and testing of four commercial prototype UHCI equipped wheelchairs has been received from the VA Rehabilitation Evaluation Unit in Baltimore. Eureka Laboratories of Sacramento was competitively selected to manufacture these devices. The first unit is currently undergoing human subject evaluation at the VA Medical Center in Richmond. After this first pilot study, the evaluation program will continue at VA Centers in Augusta, Houston, and Tampa.

Future Plans/Implications—The evaluations have been completed and a final report is to be published. That document will summarize the results of the study and contain a recommendation regarding the prescription of electric wheelchairs using the UHCI technology for appropriate severely disabled veterans. If an approval is forthcoming, Eureka Laboratories has indicated that they will pursue mass production of the UHCI to satisfy the demand of the VA and other potential purchasers.

A Request for Evaluation was written in response to a request from the Rehabilitation Evaluation Unit in order that they may use the UHCI for computer access applications.

Recent Publications Resulting from This Research
Electric Wheelchair Controllers: Effect of Speed and Acceleration on Driving Performance

Hugh Stewart, B AppScOT; Barry R. Seeger, PhD
Rehabilitation Engineering Division, Regency Park Centre for Young Disabled, Kilkenny, SA 5009 Australia

Sponsor: Channel 7 Children’s Medical Research Foundation of S. Australia

Purpose—The purposes of this study are to: 1) determine if adjustable wheelchair control parameters actually improve wheelchair driving performance of children with cerebral palsy; and, 2) determine a procedure for adjusting wheelchair controller speed and acceleration to obtain optimum driving performance. The outcome will be a protocol for establishing optimum controller settings in order to maximize benefits to users of electric wheelchairs.

Progress—A number of subjects with cerebral palsy began trials in August 1990 using a wheelchair and a standard wheelchair joystick augmented to incorporate independent settings for maximum speed and acceleration. The controller utilizes velocity feedback from optical shaft encoders fitted to each motor.

A standard test track incorporating a number of driving tasks has been developed. This allows a grading of the driving task to accommodate a range of competence levels.

Methodology—There are several phases in the experimental protocol.

Baseline. The clients perform a series of circuits of the test track in their own electric wheelchair from which lap times and errors are recorded. The client’s wheelchair is then measured for speed and acceleration and these settings applied to the trial chair. The client then performs a similar number of baseline trials using the trial wheelchair.

Optimization of Speed and Acceleration. The client is seated in the trial wheelchair, speed set to minimum, and acceleration varied through five settings, with two laps at each setting. The optimal setting to produce the fastest lap time is then decided upon. This setting of acceleration is used and the speed is varied through five settings for two laps at each setting, and an indication of optimum speed can be gained. This iterative process continues until an optimum setting of speed and acceleration is achieved.

Comparison of Optimum with Baseline. This optimum value of speed and acceleration is then compared in an alternating treatment design with a value of speed and acceleration which approximates that of the controller currently used by the subject. This process will allow us to determine if the optimum setting of speed and acceleration does in fact provide a significant improvement in driving performance.

Implications—The variable parameters of microprocessor-based electric wheelchair controllers are often poorly understood and used by clinicians. This project will provide a standard procedure by which these parameters can be optimized.

Future Plans—Client trials and final report were completed in December 1990.

Isometric Joystick Versus Displacement Joystick for Simulated Wheelchair Control

Hugh A. Stewart, BAppSciOT; Glenda Noble, BAppSciOT; Barry R. Seeger, PhD
Rehabilitation Engineering Division, Regency Park Centre for Young Disabled, Kilkenny, SA 5009 Australia

Sponsor: Channel 7 Children’s Medical Research Foundation of S. Australia

Purpose—The purpose of this study was to evaluate the performance of children and adolescents with cerebral palsy using an isometric joystick and compare it with their use of a displacement joystick.

Methodology—The experiment was conducted in two phases. The first phase was designed to give the subjects practice using the isometric joystick and to determine the most appropriate sensitivity setting for the client. This
phase consisted of 15 sessions at which 5 sensitivity settings were presented in random order. These settings were selected to correspond to 25%, 50%, 100%, 200%, and 400% of the force required to give maximum deflection of the standard displacement joystick. At each sensitivity setting, the subject had to complete three trials of four targets on the Skill Evaluator and Trainer—an input device evaluation apparatus that we developed.

Following these sessions, the most appropriate setting for the subject was chosen depending on performance (response time and number of errors) and the client’s personal preference.

The second phase of the research involved an alternating treatment design using the conventional displacement joystick and the isometric joystick at the subject’s preferred setting. Subjects attended 15 sessions at which the joysticks were presented randomly, 1-minute practice allowed, and then three trials of four targets were completed.

Preliminary Results—A pilot study involving a nondisabled adult has been completed. This was followed by an evaluation of six subjects (five adolescents and one child), three of whom have athetoid cerebral palsy, and three with spastic cerebral palsy. These have been completed and the final data are now being evaluated.

Results for the nondisabled pilot subject indicate a clear preference for the displacement joystick. Two other subjects have completed the trials. One with spastic quadriplegia and previous experience using a displacement joystick to control her wheelchair demonstrated a clear preference for the displacement joystick in the trials. The second subject (with athetoid quadriplegia), who uses foot switches to control his wheelchair, demonstrated a preference for the displacement joystick, but it was not a marked difference. All subjects who have completed trials on the first phase of the project have shown better performance using the heavier sensitivity settings. Two of the four subjects have used Setting Five (four times the amount of force needed to operate the displacement joystick) and one used Setting Four (twice the force required to operate the displacement joystick).

Five subjects began experimental trials in July 1990 and one other began in August 1990. All trials were scheduled for completion by October 1990 and a report was to be written shortly thereafter.

Implications—The isometric joystick has a great deal of face validity as a tool for clients with cerebral palsy. This project will provide empirical data to evaluate its use.


G. Verburg, MA; M. Milner, PhD, PEng, CCE; A. King, MA
Hugh MacMillan Rehabilitation Centre, Toronto, Ontario M4G 1R8 Canada
Sponsor: National Health Research and Development Programme, Department of Health and Welfare, Canada; Rick Hansen Man-in-Motion Legacy Fund

Purpose—The objectives of this two-year project are to: 1) evaluate an advanced model of a wheelchair-mounted robotic manipulator arm in two settings—an independent living and vocational environment of adults who are physically disabled, and a classroom in a school for physically challenged children; 2) determine the nature and types of activities a user would wish to be able to perform with the help of a manipulator arm; 3) analyze the control commands in order to extract common command sequences that define distinct movements of the arm and/or gripper (e.g., move up and grasp, grasp and turn, fold arm, high reach, and other more functional activities); and, 4) cooperate with the designers of the manipulator system to develop and implement an advanced control system to increase the efficiency with which persons can use the system.

Methodology—The MANUS project plans to follow six adults and six children as they use the MANUS for their daily activities and structured tasks. A camera system will be used to document actions carried out and joystick commands issued by the user to control the MANUS.

Progress—The project commenced in July 1990 using a prototype model of the MANUS arm. One subject is currently evaluating the system, and two subjects who are ventilator-dependent will begin training shortly.
[587] Adaptive Speed Control for Electric Wheelchairs

R.M. Inigo, PhD; Karim Shafik, MS
University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose/Progress—A microcomputer-based adaptive speed control for electric wheelchairs had been developed and implemented at the University of Virginia Rehabilitation and Engineering Center over a period of several years. The system was based in the Z80 microprocessor which had become obsolete.

The system has been updated using an 8086-based microcomputer. The single board computer used—the LPM SBC V40 microcomputer—was chosen for several reasons: it is 16-bit, it has on-board memory, dual serial I/O, counter/timer, and several other features which the Z80 lacked. In addition, it has a speed twice that of the Z80 and is IBM/AT-compatible, thus simplifying program modifications and data transfer to the host for analysis (during development or updating of control software).

To make the system state-of-the-art, new features have been added, such as an ultrasonic obstacle detector (as a safety enhancement), and a tiltometer to stop the chair operation if it reaches dangerous tilt-speed combinations, etc.. The control program itself has been improved to decrease the chance of malfunction. The error terms (i.e., the difference between the commanded speed and the actual speed) controls the command to the motor; a significant improvement stops the chair automatically when the error terms reaches a dangerous level.

The system has been installed in an Everest & Jennings chair and tests have been conducted with satisfactory results.

[588] An Improved DC-DC Converter

R.M. Inigo, PhD; Collin Park, BSEE
University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose/Progress—The University of Virginia Rehabilitation and Engineering Center has been investigating dc-dc converters (the electronic device that produces a variable magnitude dc voltage from the fixed 24 volts battery voltage) for several years. The most important characteristic of a good dc-dc converter, in addition to high reliability, must be high efficiency, in order to maximize chair operation before battery recharge. The previous version of the dc-dc converter that was designed, constructed, and tested at the Center satisfied the above characteristics and was all-solid-state, but used both n-channel and p-channel power transistors, an undesirable necessity. The recent availability of new integrated circuits, namely the IR2110, has made it possible to use n-channel power transistors only. This improves efficiency, reduces the component count and consequently increases reliability.

The new dc-dc converter has been tested and installed in an Everest & Jennings wheelchair with an improved adaptive controller. The chair has been tested in the field with very satisfactory results.

[589] Brushless DC Motor Evaluation

R.M. Inigo, PhD; Fred Powell, BSc
University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose/Progress—Traditionally, electric wheelchair propulsion systems have used permanent magnet (pm) direct current (dc) servomotors. These motors use a commutator to reverse the armature winding polarity as the motor rotates. In spite of their excellent torque/speed characteristics and relatively good efficiency, pm-dc motors require significant maintenance because the carbon brushes used to make contact with the commutator
wear out and have to be replaced. The commutator itself suffers the same problem, at a slower rate.

A relatively new type of dc-pm motor without a commutator is now commonly available. In this motor, the pm is in the rotor, and the armature windings are fixed in the stator. Commutation is achieved by electronic means, instead of a mechanical device. The use of modern integrated circuits for this purpose has several virtues: the circuit is very reliable, practically maintenance-free and simple. It is also inexpensive. The motor itself, due to its lack of mechanical parts (except the bearings), is very long-lasting and comparable, in this respect, to the ac induction motor. The electronic controller-driver is simple and has very high efficiency. We have evaluated the characteristics and performance of brushless dc-pm motors and found them satisfactory for wheelchair propulsion. We are now evaluating the performance of the motors installed in an electric wheelchair.

[590] Reliable, Available, and Safe Electric Wheelchairs

J.H. Aylor, PhD; John J. Thacker, PhD
University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903
Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The overall objective of this research effort is the application of state-of-the-art engineering techniques to the development of safe and highly available powered wheelchair systems. Although the development process consists of numerous distinct efforts, the ultimate goal is the development of a prototype of the next generation powered wheelchair. The new design will experience fewer repairs, less down-time, and safer operation.

Methodology—The actual effort is broken into five phases: dependability analysis (measured in terms of reliability, availability, and safety), frame and tire durability modeling, system study, bench prototype of system components, and powered wheelchair prototype. Results to date fall into two areas: analysis tools and implementation.

A unique personal computer-based dependability analysis software system, written in C and using a VGA color display, has been developed for the analysis of wheelchair systems. Models of systems containing both electronic and mechanical components are possible. The analysis algorithms are based on Markov model representations which are either pre-stored in a library or can be easily entered by the designer. A novel technique for structural reliability analysis, based on random vibration analysis, which results in a failure density function for the structure, has been developed. This new technique provides the ability to generate a Markov model for the structure, which can then be incorporated into the wheelchair system model.

Progress—Initial implementation of the prototype has begun through the development of an architecture (and prototype) for a fault-tolerant dc-dc converter. Reliability and cost analyses of numerous configurations based on complementary metal oxide semiconductor (CMOS) power devices were conducted. A new design which uses two additional transistors, only n-type devices, and passive redundancy to improve reliability was selected for inclusion in the new wheelchair controller.

[591] Research on Wheelchair Frame Modeling

J.D. Baldwin, MS; James J. Kauzlarich, PhD; John G. Thacker, PhD
University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903
Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The effort to improve the modeling of wheelchair frames has centered on developing techniques for assessing the accumulation of fatigue damage in the metal structure and incorporating the method into the wheelchair system reliability analysis system that has been under development at the University of Virginia Rehabilitation Engineering Center (UVA-REC) for the past several years. The structural reliability analysis computations are
in a form that can now be directly integrated into the Markov models used to determine the overall reliability of the power wheelchair system.

The wheelchair frame reliability problem can be stated as: “given that the loads acting on the wheelchair frame vary randomly and cause randomly varying states of stress and strain in the structure, and given that the pertinent material properties used in a fatigue analysis are known to be random-valued quantities, and given that the accumulation of fatigue damage in nominally identical structures varies randomly, determine the probability that a structure has not failed a given time in the future.”

A solution to the fully random fatigue problem has not been achieved at this time. The solution procedure developed here employs the simplest fatigue damage accumulation model and the most tractable model for the time-dependent structural strain random process and assumes that the material ultimate strength is a random variable. The result is a closed form statement of the probability density function of time to failure of a given structural detail.

If we assume that the accumulation of fatigue damage in a metal structure is adequately described by a S-N curve that is linear in log-log coordinates and the Palmgren-Miner linear damage rule, and that the time history of the strains at any given point in the structure is adequately described by a stationary narrow-band Gaussian random process, the probability density function for the time to failure of the structural detail can be described.

The statistical natures of the material ultimate strength and the stress occurring at a given point in the structure are accounted for in the statistics of the S-N curve parameters. The variability of the stress acting within the structure is the result of statistical variations in the member dimensions (i.e., tube diameters), variations in the loads acting on the structure (i.e., weight of wheelchair occupant), and of variability in the value of the material’s modulus of elasticity. To simplify the analysis, all of these parameters are assumed to be normally distributed and the algebra of normal variables is used to derive the expressions for the statistics of the S-N curve parameters.

**Results**—In order to demonstrate the structural reliability calculations, a finite element model of a standard folding frame electric wheelchair was analyzed. The highest von Mises stress point was found to be in the cross tubes at the point where they cross; the maximum stress calculated was 22,470 psi. The through hole in the tube causes a static stress concentration factor of 3.924.

Using the statistics for the large diameter tubes, occupant weight, and modulus of elasticity listed above, the standard deviation of the static stress at any point in the structure was calculated by perturbing each random design parameter in turn, and determining the variation in stress caused by each perturbation. For the power wheelchair under consideration, the standard deviation of the stress at the cross brace connection point was calculated to be 2,426.7 psi.

With the statistics of the pertinent design parameters known, the evaluation of the probability density function was performed, thereby giving a failure rate. The failure rate does not follow the classical “bathtub” curve typically assumed in electrical and electronic reliability studies. The failure rate for the structural component consists of a period of essentially zero failures, a period of nearly linear increase, and a period of rapidly rising value. The monotonically increasing failure rate is what would be expected from a metal component undergoing fatigue damage accumulation over time.

The method developed for assessing structural reliability under random loading is straightforward to apply and can provide a useful measure against which to compare competing structural designs. Because of the simplifying assumptions incorporated in the analysis, the computed values of structural reliability may be subject to some error; the value of the method lies in its simplicity and its ability to provide a measure of merit for structural design.

**Recent Publications Resulting from This Research**

Structural Reliability Analysis of Power Wheelchair Frames.
The MIT Damped Joystick: A Control Interface for Tremor-Disabled People

Purpose—The intention tremor or cerebellar ataxia often seen in people with multiple sclerosis and head injury precludes independent motor activities of many kinds. In particular, use of joystick-controlled powered wheelchairs is commonly ruled out because of unacceptable inaccuracy of steering and speed control caused by the tremor. While several available chairs include electronic filtering as a feature, this has disadvantages, including failure to deal with the visible shaking of the user's hand. To deal with this problem, the tremor group in the Newman Lab has developed a joystick which incorporates viscous damping. It does so by means of a simple chamber of 2,500,000 centistoke silicone grease through which an extension on the joystick shaft moves as the joystick handle is moved. One hypothesis is that unlike downstream filtering, this energy-dissipating load will have a compensator-like effect on the neural control loops generating tremor so that the oscillatory muscle torques driving the tremor will be reduced rather than opposed.

Progress—Objective tests have been conducted in video tracking and “driving” tasks with a small number of tremor-disabled subjects. The results showed statistically and clinically significant reduction in tremor and improvement in signal-to-noise ratio. Some of the data indicated that an optimal level of damping had been found at an intermediate value between the maximum and the minimum to which the joystick can be set. Subject reactions to the joystick have been highly favorable.

Future Plans/Implications—A protocol has been developed for simple clinical evaluation of wheelchair driving skill using the joystick. This experimental plan involves measurement of a “Fitts’ constant,” relating the required accuracy of steering task to the speed with which it is performed. It is hypothesized that this constant will be improved by the optimal amount of damping (i.e., that for a required accuracy, greater speed will be possible).

A third iteration of the joystick design is being prepared which will provide the same adjustability as the present unit in a smaller package. The new version will also permit easy exchange of handles for different users, and will improve ease of manufacturing.

Recent Publications Resulting from This Research

Patents

Development of a Smart Wheelchair

L.W. Korba; P.J. Nelson; S. Lang; D. Green; R. Liscano
National Research Council of Canada, Ottawa, Ontario K1A OR8 Canada

Purpose—This effort is directed toward improving the navigability and safety of powered wheelchairs. Of particular interest are techniques that make powered wheelchairs easier to use. New developments in this area will make powered mobility accessible to those who have both motor and sensory disabilities.

Methodology—A network of interested parties has been assembled to work on various aspects of this problem. The network includes: Hugh MacMillan Rehabilitation Centre (HMRC), Toronto; Bloorview Children's Hospital, Toronto; Everest & Jennings Canadian Ltd. (E&J), Concord, Ontario; and other interested parties. A survey
of current users of powered wheelchairs, plus potential users of sensor-enhanced wheelchairs, is underway at the HMRC (under contract from NRC). The aim of this survey is to determine the most serious problems with existing powered wheelchairs, and to find the most appropriate enhancements. The survey will cover a variety of client populations, including the physically handicapped, developmentally delayed, sensory impaired, and elderly, as well as prescribers of mobility aids. It will also attempt to determine the problems encountered by users of powered wheelchairs in a variety of transportation settings.

A basic requirement for the enhanced powered wheelchair is the ability to sense the environment. To accommodate this function, an obstacle detection and odometry subsystem which can be attached to a conventional powered wheelchair is under development. The system will provide a flexible set of intelligent sensors (self-testing and diagnosing) that can be attached at different locations on the wheelchair. A separate controller operates each sensor and communicates with a master controller. These sensors will provide basic obstacle detection and navigational improvements for the powered wheelchair.

To test concepts for the smart wheelchair, a laboratory development system has been established. The vehicle used is a Cybermation K2A Platform (3-wheeled, synchronous drive and steering, two DC motors). A key element in the development system is a multiprocessor VME computer system, running under a multitasking, multiprocessor operating system called Harmony. Two types of range sensors are currently used on the platform: a sonar sensor system consisting of 24 polaroid ultrasonic sensors arranged in an even radial pattern around the Cybermation platform and a laser ranging system.

**Recent Publications Resulting from This Research**


**Identification of Desirable Features of a Smart Wheelchair**

Stephen Naumann, PhD, PEng; Geb Verburg, MA; P.J. Nelson
The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario M4G 1R8 Canada

**Sponsor:** National Research Council of Canada, Medical Engineering Section (D.E.E. Laboratory for Biomedical Engineering); Everest and Jennings Canadian, Ltd.

**Purpose**—This is a collaborative research and development project on the “Smart Wheelchair.” Researchers are engaged in a study of powered wheelchairs to determine which smart features are most needed by persons with particular disabilities. A smart wheelchair is any powered chair or scooter which has been augmented with robotic-like sensors, and additional hardware and/or software, so that the resulting system is safer and easier to operate when compared to a conventional wheelchair. Part of this study consists of a survey that will address: 1) problems experienced with current powered wheelchairs; 2) problems encountered in traveling with powered wheelchairs; and, 3) features required in a smart wheelchair to resolve these problems and increase the usability of wheelchairs.

**Progress/Methodology**—Before surveying users and prescribers of powered chairs, the researchers performed a literature review of research in, and surveys about, wheelchairs and smart wheelchairs. Focus groups were organized and attended by wheelchair users, prescribers, engineers, and project staff. The groups identified issues and features for inclusion in a survey to be mailed to approximately 350 users and 150 prescribers of powered chairs. This paper concerns the results of the focus group meetings.

As of Fall 1990, two survey forms were completed, one for wheelchair users and another for prescribers, dealers, and vendors of wheelchairs. Eight hundred and fifty user-surveys have been distributed across Canada, and 200 prescribers and 150 dealer/vendor surveys have been sent out.
Five focus groups were held, each with a different group of users and clinicians. Forty persons attended the sessions. Fourteen people used a powered wheelchair, 17 were prescribers, developers, or manufacturers (occupational therapists, engineers, clinicians), and five were government officials. The first four focus groups addressed mobility needs of four distinct populations of disabled individuals (i.e., persons who are physically disabled, developmentally delayed, elderly, and persons who are visually impaired or blind). Participants of the fifth group discussed transportation issues.

All participants in the focus groups received three lists of issues pertaining to problems with powered chairs, transportation, and a list of potential smart features. During the focus group sessions, each participant was asked to address each list of topics for 5 to 10 minutes. At the end of the first four meetings, participants were asked to prioritize the issues that concerned them most. Group discussions occurred in which staff members participated and recorded the issues raised. The compiled notes give an initial indication of the issues of concern and of the desired smart features.

Results—The three lists of issues, compiled from the literature, consisted of 180 items in the above-mentioned categories of “problems with powered chairs” (120), “problems with transportation” (2), and “smart features” (40). The extreme difference in these numbers reflects the amount of attention given to chairs in general, compared to that given to published material on the smart wheelchair, or about the transportation of powered chairs. Literature on the smart wheelchair is relatively scarce due to the novelty of the concept and the limited extent of commercial implementation. The issues regarding transportation often revolve around two or three explicit problems of long standing (i.e., tie-down systems in buses, chair and battery transportation on planes, and accessibility of public transportation). A distinction is made between smart and traditional features, corresponding to smart and traditional chairs.

[959] Further Development and Clinical Testing of a Multifunction Vehicular Interface Unit for Quadriplegic Drivers

Stephen Naumann, PhD, PEng; Martin Mifsud, EEngT; Stephen Farr, DComp Tech; Margaret Young, OT(C);
Dieter Frensel
The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario M4G 1R8 Canada

Sponsor: Ontario Ministry of Transportation and Communications

Purpose—The objective of this project is the further development of an interface unit which provides physically impaired persons with access to secondary vehicular functions (i.e., turn signals, horn, wipers, etc.) and to evaluate the person’s ability to operate the system under simulated driving conditions.

Driving allows physically impaired individuals freedom of movement within the community—freedom to pursue educational, social, vocational, and recreational pursuits. Alternate forms of public transportation often do not allow for this independence.

Commercial systems exist that allow for adaptations to a vehicle’s steering, braking, and acceleration systems, as well as some secondary functions. However, drivers who use these aids indicated the need to have alternative means of access to additional secondary functions that present systems cannot be adapted to provide.

The Hugh MacMillan Rehabilitation Centre received funding to develop a multifunction vehicular interface unit for quadriplegic drivers. This interface unit provides the driver with access to 54 secondary vehicular functions.

Methodology—To adhere to a new alternate access system model developed within the Centre’s Microcomputer Applications Programme, a modular approach has been taken in the software design stages. The scope of changes required a redesign of the interface system. The software was written in the programming language C in a style wherein both the structure of functions and the calling of functions meet the model’s guidelines. Thus, the system provides support for a wide number and combination of input devices and output functions.

To provide ready flexibility in the creation or customizing of a control panel’s appearance and operation, a graphics-based development system has been created to run on the IBM personal computer family. This configuration facility allows for the development of the access system. The number and type of input switches can be defined, as well as the placement of the output indicators.
displayed as objects on the screen. These can be labeled and located according to priority of use. Attributes of all input and output objects (i.e., momentary and alternate action) can also be defined. Scanning paths can be described to best meet each operator’s abilities.

Functions to be accessed are grouped according to priority of use (i.e., windshield wipers have more priority than door locks) as well as to the user’s preference. Access to functions are provided through a minimum of three switches in combination with scanning, by direct selection of individual functions if switch sites accessible by the user are available, and by direct switch selection to all 54 functions displayed on a control panel.

**Results**—A prototype has been developed that includes a 54-function access method system based on a STD-BUS controller and a configuration development system. This provides a simple modular approach to the hardware, allowing for ease of customizing to the user’s access requirements. The hardware also satisfies the extended temperature range required for operating in an all-weather vehicle (−40 through +85 degrees C).

**Future Plans**—The next stage of this project calls for clinical evaluation of the interface under simulated driving conditions. This evaluation focuses on the user’s ability to operate a scanning technique while operating a vehicle, and to identify other needs of the physically impaired driver.

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**Effects of Flexible Passive Standing in Patients with Spinal Cord Injuries**

William C. Mann, OTR, PhD; Kenneth Ottenbacher, OTR, PhD

University at Buffalo, Center for Therapeutic Applications of Technology, Buffalo, NY 14214

Sponsor: RETEC U.S.A., Inc.

**Purpose**—The purpose of this study is to examine the effect of a specially constructed wheelchair (the HiRider) for persons with severe physical limitations. The HiRider is designed to allow patients confined to a wheelchair to attain unassisted passive standing. The study has three major components: 1) the impact on physiological factors such as bowel and bladder function; 2) the use of the device throughout an individual’s acute rehabilitation; and, 3) the impact of the HiRider in an employment setting. Different methods and different subjects will be used in each component: 1) single-subject research design; 2) intensive case study with several standardized assessments and interviews; and, 3) case study with one standard assessment, self-reports and interviews.

**Methodology**—**Component 1. Physiological Effects: Single-Subject Research Design.** A single-subject experimental design will be used to compare the HiRider and a standard wheelchair; the design selected is the non-concurrent multiple baseline across subjects. It will include reversal phases to increase the inferential confidence associated with any positive (or negative) outcomes. This design is intended for use in settings where several patients with similar characteristics are not simultaneously available. Three similar subjects will be randomly assigned a predetermined baseline period, followed by alternately introducing and withdrawing the intervention.

The baseline (B) condition involves use of the patient’s standard wheelchair. In the intervention (C) phase, the standard chair is replaced with the HiRider for 3 weeks. The initial B phase for each patient varies from 5 to 15 days, and is randomly assigned to the patients as they become available. All subsequent B phases are 3 weeks in length.

Three subjects are participating in this study. They meet the following criteria: 1) spinal cord injury between C6 and T12; 2) currently completing inpatient rehabilitation program; 3) male; 4) between 15-40 years of age; and, 5) medically stable.

During baseline, the patient continues to use his standard wheelchair, and information on the following outcome measures is recorded:

- **Blood Pressure.** Blood pressure is recorded on a daily basis.
- **Arterial Blood Oxygenation.** The Pulse Oximeter (Ohmeda, model 3760) is used to collect information concerning pulse rate and arterial oxygen saturation.
- **Bladder Function.** The volume of urine discharged at each catheterization is recorded.
- **Bowel Function.** The frequency of bowel movements is recorded in the patient’s chart across all phases of the study.
- **Decubitus.** Inspection for unusual or abnormal skin redness (nonblanchable erythema, a precursor to decubitus)
is conducted and recorded. The recording consists of a simple yes/no judgment.

Muscle Atrophy. Two measurements of muscle bulk on each leg are taken daily.

The outcome measures are recorded consistently across all phases of the design. In the C phase, the patient begins using the HiRider for 3 weeks; at that time the chairs are switched again and the patient returns to his standard chair. The outcome measures continue to be recorded as in the (B) phase.

Data from all primary (repeated) measures will be graphically presented and visually analyzed. Celeration lines will be computed as adjuncts to visual analysis to help identify trends within and across phases for a single subject. In addition, a randomization test will be computed for all primary (physiological) measures to statistically analyze data from replicated ABAB designs across independent subjects.

Component 2. Impact on Acute Rehabilitation. One subject will be studied in an intensive case study approach, providing a descriptive analysis of the impact of the HiRider during an individual’s acute phase of rehabilitation—up to the point of discharge. Measures will be taken on a scheduled basis; the patient will be interviewed three times each week. The subject will receive training on the use of the HiRider, and for the first month will be left on his own to determine how often he uses it, and how much he uses it in the standing position. If, after the first month, the amount of standing time appears inadequate, the subject will be counseled on the importance of standing and given a recommended schedule. There are four measures to be taken: 1) device utilization; 2) physiological areas; 3) psychological; and, 4) other.

We will determine how often the HiRider is used in the standing position, the seated position, and in both (horizontal) motion, and in stationary position and distance traveled. This information will be examined against the physiological, psychological, and activity level measures, and related to the interviews. The interviews will be structured to follow up with questions on device use that relate to distance (where traveled), and standing (what did you do in the standing position), energy expenditure, and age equivalent, and estimates of potential and current oxygen consumption.

Component 3. Impact on Employment. The ICD Survey of Disabled Americans (1986) found that 67% of working age individuals with disabilities were not working, even though most expressed an interest in working. The HiRider has the potential to increase a person’s ability to complete work-related tasks.

Future Plans/Implications—This case study will examine the impact of the HiRider on a person confined to a wheelchair. A HiRider will be placed in the person’s work setting for him to use while on the job. Device utilization will provide a baseline of information on how often the HiRider was used, how far it traveled, and the amount of time it was used in standing versus seated position. Several measures will be taken routinely, including hours worked, quantity of work, ease of completing tasks, fatigue, and stress. Stress will be measured with the Occupational Stress Inventory, a standardized assessment. The other measures will be taken with a self-report form. To validate the self-report measures, a therapist will do monthly interviews covering the same areas, as well as additional questions on use of the HiRider in the work setting. In addition, the subject’s work colleagues will be interviewed to obtain co-worker perspective on the impact of the HiRider in the workplace.

C. Seating Systems

[597] Computerized Shape Reproduction for Custom Contoured Wheelchair Seating Systems

Steven I. Reger, PhD; Richard R. Navarro, MSME; Donald C. Neth, MSEE
The Cleveland Clinic Foundation, Department of Musculoskeletal Research, Cleveland, OH 44195-5254

Sponsor: Cleveland Clinic Foundation Research Institute

Purpose—The medical necessity for custom contoured wheelchair seat and back supports has been widely recognized in recent years. Until now however, the cost, accuracy of fit, and timeliness of fabrication have been
obstacles to widespread use of contoured supports. The objective is to apply computer technology to the shape-sensing and fabrication aspects of the dilatancy molding system.

Methodology—A shape sensor, consisting of a linear array of 32 potentiometers interfaced to an A/D board provides digital storage of seat and back contours developed in a simulator. Software has been developed for a 3-dimensional graphic display and on-screen shape modification. A modem transfers data from the molding session to a central fabrication site. Contours are then cut from polyethylene foam blocks after a subtraction software routine makes allowance for a soft foam liner. A PC-driven 3-axis milling machine is used for fabrication. The custom contours are then shipped to the therapist or DME dealer location for mounting in the mobility base. Shape fabrication can be accomplished in less than 1 hour with accurate results.

Results—A pilot study using the computerized shape reproduction system was conducted with 7 MR clients ranging in age from 14 to 28 years. Results to date are encouraging. Assessments were conducted to evaluate postural support and residual function with clients in the sitting position. Clients with varying disabilities including cerebral palsy, spina bifida, and spinal cord injury have been seated using this technique. Improved posture of the spine and upper body function were apparent without the loss of trunk stability. The reduction in peak interface pressures were added benefits of the contoured system with these clients.

Future Plans—The technology has been developed to the point where field-testing of the hardware and software is scheduled to begin. Continued data collection from field use will further demonstrate the benefits of contoured body supports.

[598] Development and Clinical Evaluation of an Adjustable Modular Postural Seating System for Persons with Mild to Severe Physical Involvement

Sheila Jarvis, BSc, OT(C); Wallace Lotto, MD, FRCS(C), FACS; Stephen Naumann, PhD, PEng; Steve Ryan, BESc, PEng; Ihsan Al-Temen, PEng; Ariel Ataides; Diana Fong, BSc, MA, OT(C); Egon Frenzel; George McMillan
The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario M40 1R8 Canada
Sponsor: National Health Research and Development Programme, Department of Health and Welfare, Canada

Purpose—The purpose of this study is to develop and evaluate a cost-effective seating system that will interface with a wide range of available seating components, require few parts, and be easy to dispense with readily available tools.

The specific goals are to: 1) develop and evaluate a system of adaptable, pre-molded plastic shells; 2) develop and evaluate a foaming system compatible with the shell system; and, 3) prepare and evaluate a training package to assist seating clinics in dispensing the system.

Methodology—A working model of the core components of the pre-molded shells has been created. The system consists of a back pan, seat pan, and interfacing hardware.

Back shell. This component is a simple, one-piece, three-sided thermoformed pan made of ABS which is intended to be produced in three widths. The side panels and back height are oversized to enable customization of the pan by trimming. It is configured to locate between the uprights of the wheeled base. Inclination of the pan is provided by the interfacing hardware.

The back shell is secured by two sets of hardware. The upper set is semipermanently attached to the wheelchair push handles, and the lower set is attached to the back shell to avoid interference with the upright bushings as the chair is folded. To insert the back shell, the locking tabs on the lower clamps are released, and the torque knobs provided on the upper clamps are unscrewed. By pivoting the back about the upper clamp axis, the back shell can be removed.

Seat shell. This component is a molded ABS member with a lip on one side designed to friction-fit onto the rails of the wheeled base. It is provided with a 2-inch drop to avoid interference with the wheelchair cross bars.

Progress—Suitable interfacing hardware for securing the seat pans is currently under development. The seat shell is configured to accept commercially available cushions or polyfoam cushions. The simple polyfoam cushions will be made in predetermined sizes and upholstered. Provisions for adding a headrest and contoured laterals on the back shell and a footrest on the seat shell will also be made for the “next generation” prototype.
Future Plans—Once the shell arrangements have been finalized, a unique foaming procedure will be established for use with the system. After evaluation of the prototype design through clinical field trials, assessment of instruction and training manuals will follow. The technology will be transferred to Variety Ability Systems Incorporated (VASI) for manufacture and distribution.

[599] Toward Development of a System for Safely Transporting Physically Disabled Children in Passenger Cars

Wallace Lotto, MD, FRCS(C), FACS; Stephen Naumann, PhD, PEng; Steve Ryan, BEng, PEng; Diana Fong, BSc, OT(C); Louie Scalabrelli; Mary Young, OT(C)
The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario M4G 1R8 Canada
Sponsor: National Health Research and Development Programme, Department of Health and Welfare, Canada

Purpose—The purpose of this project is to provide protection, consistent with child restraint systems currently used in automobiles, for young children with physical disabilities. The specific goals are to: 1) develop a system for converting a commonly dispensed seating insert into a proven child restraint system; 2) create an education program to provide instruction to parents on the correct use of the system as a child restraint; and, 3) implement a quality assurance plan to ensure that a consistent level of system performance is achieved for the production version.

Physically disabled children often require specialized systems as a means for obtaining proper postural support and providing an opportunity for increased function. Available automobile child restraint systems offer insufficient support for many of these children. Therefore, parents often use the insert from the child's seating system for this purpose, although inserts do not provide adequate protection against automobile collisions.

Methodology—The system for converting a customized seating insert into a child restraint system consists of a triangulated, tubular frame, a restraint belt arrangement, insert interfacing hardware, and a tether strap. The structural component of the conversion system is an arrangement of tubular steel configured to rest on the car passenger seat and be the primary load-bearing structure responsible for “riding down” car deceleration. The frame provides anchoring points for the occupant shoulder harness, crotch belt, and tether strap. It is also designed to interface the postural support device to the passenger seat. The frame and seating insert are anchored to the car through the lap belt provided at that passenger seat location. The tether strap, which is anchored to the car body, is also included at the upper end of the frame to preclude excessive pitching of the restraint system and thus limit head excursion in the event of a motor vehicle accident or abnormal car maneuver.

The restraint belt distributes the impact forces over a large area of the child's body. The insert interfacing hardware is designed to isolate the securement of the child from that of the insert.

Future Plans—Impact tests will be conducted at the Downsview Civil Institute and Environmental Medicine Impact facility to verify the dynamic performance of the system. In addition, an education program will be developed to instruct parents on how to properly use the system.

[600] Functional and Clinical Evaluation of the Short- and Long-Term Effects of Anteriorly Tipped Seating in Children with Cerebral Palsy

Morris Milner, PhD, PEng, CCE; Wallace Lotto, MD, FRCS(C), FACS; Ruth Koheil, DipP&OT, BSc(PT); Alex Sochaniwskyj, BSc, BASc; Kazek Bablich, MSc, RPT; Denise Reid, PhD, OT(C)
The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario M4G 1R8 Canada
Sponsor: National Health Research and Development Programme, Department of Health and Welfare, Canada

Purpose—The objective of this study is to observe the effects of altered sitting positions on trunk stability, breathing patterns, and hand/arm function.

Methodology—The first part of this study compared functional parameters such as tidal volume, respiration rate, minute ventilation, trunk stability, and hand/arm
goal-directed velocity between a group of eight non-neurologically impaired (normal) children and a group of eight children with cerebral palsy, under different seating conditions.

The second part of the study examined the long-term effects of a 10-degree forward-tipped chair seat on 10 children with cerebral palsy. Following an initial assessment, adjustable tilting seats were provided for use by the children in a classroom for a period of 8 weeks, at which point the children were reassessed. During the following 8-week period, the children sat on their regular seats, after which they were assessed a final time.

Results/Implications—Short-term effects. Normal children exhibited a lower respiration rate than children with cerebral palsy in both the horizontal seat base and anteriorly-tipped seat base conditions. For the normal children, tilting the seat forward caused an increase in the respiration rate but a decrease in the tidal volume. The resulting effect was a decrease in minute ventilation. In children with cerebral palsy, a tipped seat caused an increase in tidal volume which resulted in an increase in minute ventilation. It appears that forward-tipped seats facilitate increased diaphragmatic range of motion in children with cerebral palsy. Hand/arm targeting tests suggest that children with cerebral palsy use more space (move their hands over a longer path) in reaching for a specific target and require more time to do so, as compared to normal children. Although tipping the seat forward did not cause significantly improved targeting performance, clinical observations and a comparison of path patterns suggest that tipped seating may stabilize the trunk and improve upper extremity response efficiency.

Long-term effects. When tipped seating is used over a period of time, there appears to be a trend toward improvement of trunk stability, decreased tidal volume, and decreased minute ventilation for children with cerebral palsy. Forward-tipped adapted seating is regularly recommended and used successfully in a classroom setting for children with cerebral palsy.


Mary Cardi, MS, PT; Martin Ferguson-Pell, PhD; Jean Minkel, MS, PT; Lata Bhansali, MD
Center for Rehabilitation Technology, Helen Hayes Hospital, West Haverstraw, NY 10993

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The clinician’s capacity to provide advanced seating and positioning systems for disabled clients has grown enormously with the availability of sophisticated new commercial products and central fabrication capabilities. Custom-contoured and modular seating systems and advanced seat cushions are now being prescribed by large numbers of centers staffed by experienced clinical specialists. In many cases the process of positioning a client and defining the characteristics of the seating surface can be aided by the availability of a pressure-mapping system.

Currently, there are several pressure-mapping products available which measure the full wheelchair seat area. These systems are limited in their abilities to minimize error due to hammocking, to provide adequate spatial resolution, and to provide options to measure and record both peak and gradient pressures during functional activities.

The goal of this study is the development of a pressure-mapping system that promises a significant improvement in pressure-mapping technology. A device developed for dental occlusion pressure-mapping (Tekscan Inc., Boston), offers great promise for application in the rehabilitation field. It employs the use of advanced computer-assisted lithography to produce a grid of over 2,000 sensors on centers 1 cm apart. The sensor area is 6 square mm; the thickness of the mapping system is 200 microns on a flexible mylar matrix. The sensing element is an advanced pressure-sensitive ink with excellent resilience and hysteresis properties. Preliminary work has demonstrated the potential for producing devices with a wide range of sensitivities to pressure by redesigning the electronic conditioning and altering the proportion of the conductive constituents of the ink.

This project will use this technology to develop an advanced clinical prototype pressure-mapping system, including both the hardware and software that would be used for seating clinic applications.

Final design criteria will incorporate recommendations from leading centers experienced in interface measurements. Performance and reproducibility of the Tekscan prototype and four commercial pressure measurement
systems will be contrasted against these ideal specifications and measurements compared on four cushions of different stiffness commonly prescribed for individuals with spinal cord injury. The prototype will also be tested by clinicians for prescription of cushions for clients at high risk for ulceration, for assessment of pelvic and body alignment and prescription of wheelchair inserts for postural support, and for dynamic measurements of impact loading during propulsion.

**Progress**—A survey of recommendations for design criteria of a wheelchair mapping system was returned from nine research and clinical centers in the U.S. and abroad. Performance and design criteria for the sensing pad, data management, cost, and durability were incorporated into initial prototype development.

We are in the process of building a pneumatic testing system and contoured loader gauge with electronic transducers for calibration and assessment of hysteresis, and effects of hammocking, curvature, and prominence on map performance. An initial wheelchair map and software system has been developed. Comparative bench testing and clinical trials have not been completed, but initial experience with the system indicates significant improvement compared to other systems. The map demonstrates high spatial resolution and appropriate measurement ranges. Data presentation includes options for real-time and freeze display of both a two-dimensional (2-D) pressure map and three-dimensional (3-D) pressure contour. Dynamic loading can be measured and recorded for 6 seconds and displayed in either 2-D or 3-D modes.

**Future Plans/Implications**—Complete testing and clinical evaluation of this system will determine potential for marketing as a seating clinic and research tool.

[602] **Research and Development to Improve Seating Design**

Kao-Chi Chung, PhD; Clifford E. Brubaker, PhD; Colin A. McLaurin, ScD; David M. Brienza, MSEE; Christopher J. Hughes, PhD; Philip R. Protz, MSBME; Brenda A. Sposato, MEBME; Stephen H. Sprigle, PhD

University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

**Sponsor:** National Institute on Disability and Rehabilitation Research

**Purpose**—The purpose is to develop a new seating technology utilizing CAD/CAM for the improvement of tissue viability, body positioning, deformity management, comfort, functional ability, and mobility in wheelchairs and other seating devices. Specific objectives include: 1) study of tissue mechanics and physiology for the design of seating supports; 2) development of CAD/CAM custom seating systems for clinical application; 3) optimization of wheelchair seating, positioning, and propulsion; and, 4) information dissemination and technology transfer. The optimal goal is to provide cost-effective devices for the disabled.

**Progress/Results**—The work in progress and accomplishments are summarized as follows:

**Magnetic Resonance Imaging (MRI) and Analytic Modeling of Weightbearing Soft Tissues.** MRI techniques were implemented to quantify biomechanical properties and structure information of buttocks soft tissue in response to externally supportive loads for normal and SCI persons. The results showed that volumetric changes of fat and skin were greater than those of muscle under compressive loadings, and T₁ relaxation times were found to be statistically different between loaded and unloaded soft tissues. Therefore, the T₁ time constant could be used as an index for characterizing loaded internal soft tissues and evaluating the cushion and support materials used in seating and bedding. A method was also developed to provide in vivo three-dimensional (3-D) geometric information for finite element modeling of the weightbearing buttocks. A nonlinear model has been developed that analyzes and predicts internal tissue deformation to correlate the results from MRI measurements. Work has continued to characterize the atrophic tissues of spinal cord injury and to verify validation of the analytic modeling process.

**Evaluation of Custom Contoured Cushions (CCC).** An earlier prototype of the CAD/CAM seating system was used for both the research study and clinical seating service. In the past 12 months, more than 100 CCCs have been prescribed and provided for research subjects and clinical clients with different disabilities. The results have been encouraging for the continued development of custom seating technology. In addition, a study was conducted to
investigate geriatric seating and positioning, and the use of CCCs for nonambulatory elderly persons confined to wheelchairs. Twenty subjects over the age of 65 were randomly selected from a local nursing home. The information should be useful in identifying seating and positioning needs for the elderly. Custom seating and CCCs are likely to improve seating pressure, body posture, deformity accommodation, and comfort. Further clinical evaluation will center on cerebral palsy (CP) children and pediatric seating.

**Design of CAD/CAM Seating Systems.** A computer-aided shape sensing system using spring suspension has been developed for the determination of both custom seat contour and force distribution at the buttocks-support interface. This semiautomated system allows adjustment of individual sensor elements to prescribe the appropriate contour surface for different disabilities. A 3-axis carving system was also developed with the capability to fabricate seat cushions and back supports to a maximum depth of 8.5 inches for any surface dimensions that will fit within a 36-inch diameter circle. The system, which is controlled through a PC interface, consists of two translational and one rotary axis actuated by servo motors. Control of the axis is mediated by CNC cards installed in the PC. The time required to carve a typical wheelchair cushion is approximately 10 minutes. A comprehensive evaluation of the CAD/CAM system is being conducted at five selected rehabilitation centers for demonstration and future development of custom seating. Work is also continuing on an automated system for advanced seating technology.

**Wheelchair Propulsion.** This study was to investigate the biomechanics of levers and handrims for wheelchair propulsion and the effects of seat position and spinal cord injury (SCI) on propulsion mechanics. Six paraplegic and 9 able-bodied subjects were included for 3-D motion measures (trunk, shoulder, elbow, and wrist), hub torque and stroke arc measurements on 6 different seat positions. The joint torques were calculated from the data. Significant differences were found for changes in seat position and method of propulsion, and between able-bodied and SCI subjects. The results provide useful information for wheelchair design and seating prescription as well as development of analytic modeling for the optimization of wheelchair propulsion.

**Wheelchair Seating and Positioning.** In conjunction with the CAD/CAM seating system, a child’s adjustable wheelchair has been designed for the development of modular and custom supports for disabled children. Work is continuing in the study of trunk support and the effects of body support and positioning on muscle activities and functional abilities in cerebral palsy children.

**Technology Transfer.** Custom seating technology has been successfully transferred to the South Carolina Rehabilitation Engineering Center (SCREC) for seating services, and to Pin Dot Products (Chicago, IL), a major manufacturer of specialized seating systems. Seat contours are measured in SCREC and transmitted via modem to UVA where the custom contoured cushion is fabricated. A CCC and cover are then shipped to SCREC. In the past 12 months, the system has functioned well and 28 clients with different disabilities have been provided with a CCC. A comprehensive beta evaluation of the UVA-REC CAD/CAM seating system is being conducted at five selected Centers: Newington Children’s Hospital, National Rehabilitation Hospital, Helen Hayes Hospital, Rancho Los Amigos Hospital, and Texas Institute for Rehabilitation and Research. Pin Dot Products has also participated in all phases of this evaluation process for commercial development of the technology.

**Recent Publications Resulting from This Research**
Computer-Aided Shape Sensing for Prescribing Custom Contoured Seat Cushions. Sposato BA, Masters project, University of Virginia, 1990.
[603] Research and Development on Assessing Wheelchair Ride Quality

John G. Thacker, PhD; James J. Kauzlarich, PhD
University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—A systematic method of evaluating the ride comfort for wheelchairs is needed to provide users with quantitative evaluation information. The development of new seating systems, suspension systems, frames, and tires require in the final analysis the methodology to assess the anticipated improvements in ride quality.

Progress—The reproducibility of the ride comfort data collecting system with the treadmill test configuration has been established. Software has been written to calculate means and standard deviations of the root mean square (RMS) acceleration data for a series of constant parameter tests. The averages and standard deviations of the acceleration frequency spectrum can also be calculated from multiple tests. The results of the test show that the magnitudes of the standard deviations of the frequency spectrum stay below 10% of the mean values during severe tests. This indicates that the collection of data can be minimized and still see trends in the data. Initial floor data has been collected, but it was found to be very difficult to keep the speed at a constant value. It was also found that the rigid International Standards Organization (ISO) dummy data was totally different than the human body data. Finally, the wheelchair used for the tests only had elevated footrests, and did not represent the large population of wheelchairs with regular footrests. Invacare has recently donated a new manual wheelchair with regular footrests which will be used to collect more data.

[604] Development of a Tilting Backrest for Wheelchairs

Louis Goudreau, BASc, PEng; Harold Gay, Reg Tech; Gilbert Layeux, Reg Tech
Department of Rehabilitation Engineering, The Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada

Sponsor: The Rehabilitation Centre

Purpose—The need for a good backrest-tilting mechanism arose from concerns voiced by seating clinicians. Research and development of a safe and easy system is ongoing.

Progress/Methodology—A positive spring-loaded locking mechanism is mounted on a set of square tubing guides. The guides are fixed to the frame of the backrest, while two swiveling arms bridge the guides to the frame of the chair. A latching mechanism prevents the backrest from tilting accidentally. The system can be operated with one arm, and is now under evaluation.

[605] Biomechanical Analysis of Wheelchair Propulsion for Various Seating Positions

Mario Lamontagne, PhD; Louise Masse; Micheal D. O’Riain, PhD, PEng
Department of Rehabilitation Engineering, The Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada; University of Ottawa, Ottawa, Ontario K1N 6N5 Canada

Sponsor: University of Ottawa

Purpose—The purpose of this project was to investigate the propulsion of paraplegic persons for different seating positions.

Progress—The pattern of propulsion for five male paraplegics was investigated for six seating positions, consisting of a combination of three horizontal rear wheel positions...
at two seating heights. To simulate wheelchair propulsion in the laboratory, the wheelchair was mounted on high rotational inertia rollers. For three trials at each seating position, the subject propelled the designed wheelchair at 60% of their maximal speed which was determined at the beginning of the test session. At each trial, the subject's propulsion technique was filmed at 50 Hz with a high-speed camera for one cycle; the raw electromyographic (EMG) signal of the biceps brachii, triceps brachii, pectoralis major, deltoid anterior, and deltoid posterior muscles were simultaneously recorded for three consecutive cycles. The digitized film data were used to compute the linear and angular kinematics of the upper body, while the EMG signals were processed to yield the linear envelope (LE EMG) and the integrated EMG (IEMG) of each muscle.

Results—The kinematic analysis revealed that the joint motions of the upper limbs were smoother for the low positions since they reached extension in a sequence (wrist, shoulder, and elbow) when compared to the high positions. Also, the peak linear acceleration of the hand at the end of the recovery phase was lower, thus facilitating the contact of the hands on the pushrims at the point of grabbing because lower acceleration would reduce slippage of the hands on the pushrims. Also, the forearm linear velocity slopes and the elbow angular velocity slopes were less abrupt for the backward-low position. It was observed that in lowering the seat position less IEMG was recorded and the degrees of contact were lengthened. Among the seat positions evaluated, the backward-low position had the lowest overall IEMG and the middle-low position had the lowest pushing frequency. It was found that a change in seat position caused more variation to the IEMG for the triceps brachii, pectoralis major, and deltoid posterior. The trunk angular momentum was not found to be affected by a change in seat position which may be related to the variability among the subject's technique of propulsion or a posture compensation. Based on these descriptive observations it was concluded that the middle-low and the backward-low positions would be slightly better seating positions. Weak hip flexors are associated with class IV, and there is the possibility that some subjects adjusted their posture with a change of seat position.

Implications—The kinematic and EMG analysis of wheelchair propulsion at different seat positions has provided useful information to enhance our understanding and the development of wheelchair design. However, further studies should be conducted in this area to confirm our observations and to provide more information about the ideal seating position.