V. Wheelchairs and Powered Vehicles

A. General

B. Powered Controllers

C. Seating Systems
V. Wheelchairs and Powered Vehicles

A. General

Evaluation of the Neutral Posture for Handicapped Utilizing Wheelchairs

Michael Krebs, M.D. and Jerome J. Congleton, Ph.D., P.E.
Texas A&M University, College Station, TX 77843
Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this project was to build and fit the neutral posture chair to three wheelchairs (Amigo, Everest/Jennings, and Alexis). The neutral posture chair is a unique combination of a forward sloping cultivator seat and an English saddle, with wrap-around leg trough support.

Progress/Methodology—1) Modify and install a neutral posture chair to fit existing Amigo hardware. The chair provided pneumatic adjustment of height and, while seated, adjustment of seat pan tilt and backrest angle and included a manual lock to stop seat rotation when desired as well as optional armrests. The handle bars and steering post were modified to allow greater leg clearance, provide bend in steering post, and provide speed control linkage to handle. A deflector guard was developed for the dual rear wheels.

2) Modify Everest/Jennings wheelchair and neutral posture chair for compatible attachment. A modified wheelchair that can be collapsed and stowed in the rear seat of a vehicle by the user was provided. A Pos-chair with adjustment of independent seat pan and back rest tilt angle as well as armrest controls for actuation of seat pan and back rest tilt, mechanisms was provided. Materials and design modifications to reduce overall weight of chair was investigated.

3) Modify Alexis wheelchair and neutral posture chair. A Pos-chair was designed with electrical height and tilt actuation and a seat pan and back rest bladder system. The mounting hardware on the wheelchair was redesigned to accommodate the new Pos-chair interface and the armrest with control assembly and footrests was added.

Preliminary Results—The prototype of the neutral posture chair for the Amigo is complete and user evaluation and feedback began in July, 1987. The prototypes for the Everest/Jennings and Alexis wheelchairs were completed and the user evaluation/feedback began in August, 1987.

Future Plans/Implications—Assuming user evaluation/feedback is positive and considerable advantages can be obtained, additional funding will be sought. The neutral posture designed wheelchairs will then be compared to currently utilized wheelchairs. The scientific methods utilized will be: buttocks and thigh pressure measurements, stability of the chair and person (by measuring center of gravity), anthropometric measurements for work-place design criteria, and measuring the effect of body posture on force-generating capability.
Wheelchair Graded Exercise Test for Patients with Lower Limb Disabilities

Hines Veterans Administration Hospital, Hines, IL 60141 and Loyola University School of Medicine, Maywood, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Wheelchair locomotion even under ideal environmental conditions can result in elevated levels of exertion and fatigue. For some elderly persons, and patients with cardiovascular and/or pulmonary impairments, manual wheelchair locomotion may pose a significant health risk. If health care professionals must make judgments regarding a patient’s capacity to endure the exertional stress of operating a manual wheelchair, give exercise prescriptions for rehabilitation and/or develop aerobic conditioning regimens, they must have appropriate measurement tools for patient evaluation.

The problems addressed in research are to: 1) develop a device that will utilize the patient’s own wheelchair for graded exercise testing and aerobic fitness training; 2) establish standardized maximal and submaximal wheelchair graded exercise tests to accurately measure the cardiorespiratory fitness of patients who are restricted to the manual wheelchair; 3) evaluate the sensitivity of the testing system for detecting abnormal cardiovascular and pulmonary responses to exercise stress in spinal cord injured (SCI) and other persons with lower limb disabilities; and, 4) compare wheelchair experimental testing protocol test data against data obtained from conventional arm crank ergometry.

Progress—New experimental graded exercise test protocols are being designed and empirically evaluated. These tests are analogous to the well established procedures for lower limb exercise testing, i.e., bicycle ergometer, treadmill. Because the intensity of exercise on the Wheelchair Aerobic Fitness Trainer can be controlled it is possible to test patients with very low to very high exercise tolerance. The WAFT graded exercise protocols to be evaluated are: a) sub-maximal, b) maximal discontinuous, c) maximal continuous for the highly physically fit, d) maximal continuous for the average fit, and e) maximal continuous for the low fit and those at high risk of coronary heart disease. Exercise tests administered on the WAFT, in accordance with the established protocols, can provide valid and clinically useful information regarding the locomotor performance capacity and cardiorespiratory fitness of SCI patients and others with lower limb disabilities.

Project tasks include: 1) recruitment of an adequate sample of subjects; 2) complete modifications to the WAFT; 3) hire cardiac nurse with current certification in advanced life support; and, 4) continue laboratory bench testing of the WAFT to establish the work done by the user at different velocities and magnetic resistance settings.

Preliminary Results—A prototype device called the Wheelchair Aerobic Fitness Trainer (WAFT) has been constructed and undergone pilot testing. The WAFT was developed and is being evaluated by the Rehabilitation, Research & Development Center, Edward Hines, Jr. Veterans Administration Hospital, Hines, Illinois. This device enables the patient to use his or her own wheelchair as a means of exercise. Thus graded exercise testing on the WAFT can give a more realistic evaluation of a patient’s functional capacity for wheelchair locomotion than alternative modes of exercise. The exercise stress test protocols to be utilized in this research project were explicitly created for the WAFT. The concept of task specificity as applied to wheelchair locomotion has been of paramount importance in the development of both the testing device and the graded exercise test protocols.
Ergonomics of Manual Wheelchair Propulsion

R.H. Rozendaal; L.H.V. van der Woude; H.E.J. Veeger
Department of Functional Anatomy, Faculty of Human Movement Sciences, The Free University, Amsterdam, The Netherlands. 1007MC
Sponsor: Innovative Research Programme/Aids for the Handicapped

Purpose—Manual wheelchair propulsion is less efficient (8 percent) than other ways of human ambulation (e.g., cycling, 25 percent). The nature and causes of this apparent drawback have to be understood if optimization is to be realized.

The objective of the present research is to analyze the driver-wheelchair interface in search of kinetic, biomechanical, and exercise-physiological aspects of wheelchair propulsion on a straight trajectory and on the dependence of driver, wheelchair, and interface-related variability.

Progress—Wheelchair types were tested on a motor driven treadmill: lever- and crank-propelled wheelchairs proved to be more efficient and less energy-costing than normal hand-rim propelled wheelchairs. A special racing wheelchair appeared the least efficient (7.5 percent max). However, cardio-respiratory responses, frictional losses due to rolling drag, and air resistance were lower. Hand-rim diameter was of importance; the smaller rims leading to more efficient driving. Physiological responses and movement technique in propulsion depended on power output (velocity, resistance) and on interface factors, such as seat height and shoulder position. Speed adaptation in hand-rim wheelchair propulsion occurred primarily by adapting cycle-frequency, push-duration, and work/push. Duration of the recovery phase showed only a minor decrease, whereas the push range remained constant.

Future Plans/Implications—A wheelchair simulator will become available in late 1987. It will be computer-controlled, with dual controls and simulation systems for asymmetric driving. Force transducers in the propulsion system, as well as the seat and back rest, will enable a more thorough biomechanical analysis. Movement registration and EMG will complete the kinesiological analysis.

A Model for Optimization of Wheelchair Lever Propulsion

Clifford E. Brubaker, Ph.D. and Pradip N. Sheth, Ph.D.
University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903
Sponsor: National Institute on Disability and Rehabilitation Research: Field-Initiated Research Program

Purpose—The purpose of the project is to develop a model to predict and simulate optimum wheelchair propulsion performance, from dimensional variables and a limited number of performance factors, for wheelchair users. A necessary and more fundamental goal is the development of a model to predict individual force vectors for selected muscles of the upper extremity during a motion cycle.

There are four components of the project. These include: 1) the determination of architectural models for the selected upper-extremity muscles; 2) the acquisition of kinematic, force, and muscle-activation data for a range of wheelchair propulsion cycles; 3) the formulation and evaluation of load-sharing algorithms for the muscles during motion cycles; and, 4) the development of software for mathematical and graphical simulation and prediction.

Progress—Progress has been made in the first three of these areas. Data from cadaver dissections to determine volume, belly length, pennation angle, optimum fiber length, and length and volume ratios relative to segment lengths and joint-to-muscle attachment distances have been obtained for eight upper-extremity muscles. These data are being compared with measurements acquired from MRI scans.

The development of the architectural model is based on the work of Woitiez et al., in the Netherlands. A 3-dimensional skeletal-link model based on kinematic data has been formulated using IMP,
Wheelchairs and Powered Vehicles

a CAE software system for linkages and mechanisms. The initial model included 4 d.o.f. and 2 segments. This model is currently being extended to include motion for 5 segments (trunk, scapula, arm, forearms, and hand) with compatible d.o.f. for the involved joints. IMP is being used to formulate the equations of motion for the skeletal link model.

The IMP system has also been used to drive the link model through wheelchair propulsion cycles to calculate the mechanical advantages of the different muscles over a cycle. These data will eventually be used, along with the architectural model, to formulate the algorithms for prediction of the individual muscle force vectors.

Preliminary Results—The results obtained to date are of a preliminary nature. Dissections have been limited to two cadavers; however, the results from comparison of measurements of lengths and volume from the MRI scans with direct measurements obtained by dissection have been quite good. Mechanical advantages for simulated muscles (line forces) have been quantified as a function of joint torques about the shoulder and elbow axis in a preliminary model using the IMP system.

Future Plans—The activities to date represent less than 1 year of work on a 3-year project. More data will be collected to obtain representative values to establish ratios for the architectural model variables for the selected muscles. One task to be performed during the next period is the evaluation of several load-sharing algorithms, based on optimum control theory, that have appeared in the literature. This evaluation will be accomplished using kinematic and EMG data obtained during simulated level propulsion.

Publication Resulting from This Research


Functionality and Durability of Manually-Propelled Wheelchairs

R.H. Rozendal; L.H.V. van der Woude; M.E. Roebroeck
Department of Functional Anatomy, Faculty of Human Movement Sciences, The Free University, Amsterdam, The Netherlands, 1007MC

Sponsor: Research Programme on Quality and Functionality of Aids for the Handicapped

Purpose—The purpose of this study was to analyze individual complaints and appreciations regarding manually-propelled wheelchairs under daily use conditions, related to impairment, intensity of daily use, and wheelchair brand and type.

Progress—Instruments developed for the whole sample were: a telephone questionnaire (180 items) taken twice, a failure-diary kept during a nine-month interval between interviews, and an activity-diary during a week in Spring 1987. In 10 percent of the respondents, a technical examination of the wheelchair, and an odometer mounted to the rear wheel of the wheelchair during a nine-month period, were administered in order to validate the instruments. Samples were drawn from populations of wheelchairs provided in 1982, 1983, and 1984 by the two major social welfare corporations in this country. Non-response amounted up to 75 percent or more, resulting in a total sample of N = 609 respondents for the first telephone questionnaire.

Progress—Testing is well under way and was to be completed in the Fall of 1987.

Future Plans/Implications—The research will give answers to questions formulated, in as far as the combinations of the variables will result in a considerable number of different cases; contribute to the methodology of this type of consumer research; and provide a basis for realistic and valid lab tests on wear and tear of wheelchairs.
Development of a Motorized, Adjustable Standing Frame

P. Bowker, Ph.D. and A.B. Liggins, M.Sc.
Department of Orthopaedic Mechanics, University of Salford, Salford M5 4WT, UK

Sponsor: University of Salford Venture and Enterprise Fund

Purpose—For handicapped, as for able-bodied children, the erect weightbearing position has immense advantages in maintaining health, compared with the sedentary posture. For children for whom walking or standing is impossible or difficult, the weight-bearing position can be obtained through the use of a standing frame in which the child is held by three-point support in front of the knees and chest and behind the buttocks. Understandably, however, the daily standing session is not welcomed by these children, who see it as twenty minutes of boring, wasted time, during which they are deprived of the mobility of their electric wheelchair. The objective of this project was, therefore, to produce a motorized standing frame which combined the mobility of the electric wheelchair with the therapeutic value of the standing frame.

Progress—To date, a prototype suitable for children in the age range of 6-11 years has been designed, built, and subjected to trials with a group of handicapped children.

The prototype device consists essentially of a simple standing frame, which can be swung into the horizontal position to facilitate the fitting of the child, mounted on a motorized base. This base carries two twelve-volt traction batteries, which differentially drive two motors slung behind its rear wheels. Control is via a joystick mounted on a pivoted arm, which gives a top speed of 3.5 mph. All the components of the drive and control systems are standard electric wheelchair parts, which enables a system of proven quality to be assembled at minimum cost. The batteries and motors have a protective cover, featuring lights which flash when the batteries are in need of charging. The detachable table is suitable for schoolwork, for toys or games, or for feeding.

Preliminary Results—The frame has recently been tested with four children at a school for the physically handicapped, and although a number of detail deficiencies were highlighted, the overall concept and execution were found to be most successful. Indeed, that the device had achieved the aim of combining the mobility of the electric chair with the therapeutic value of the standing frame, was confirmed when the children who tested our prototype christened it, “The Stand-up Wheelchair.”

Future Plans—We now plan to build a pre-production model, making use of the experience gained with the prototype and improve the engineering of the main structure of the frame.

Development of a Protective Foot and Leg Guard for Use in Wheelchair Sports

S. Naumann, Ph.D., P.Eng.
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Variety Village Sport Training and Fitness Centre, Toronto, Canada

Purpose—This study had the following objectives: 1) to gather information on participation of the adolescent and teenage wheelchair population in sports activities; 2) to develop a guard which protects the lower legs and feet of adolescent and teen-aged athletes while playing wheelchair sports; 3) easily attaches to and detaches from a variety of wheelchairs; and 4) will be manufactured at a reasonable cost.

Progress—A survey was conducted of children who characterize the subject population of this project. Information from the questionnaires served to clarify the design criteria by identifying the cause and nature of injuries experienced by children playing various sports, their attitudes toward participation, and the potential for injury.

The guard is a rigid U-shaped structure, protecting but not touching the shin and calves of the child's
legs. It is constructed of a tubular aluminum frame into which is fastened a polyethylene sheet. (Different colors of polyethylene could be used to designate different teams.) Prototypes of the guard have been produced and evaluated for electric wheelchair floor hockey and manual wheelchair basketball.

This project has proceeded through the combined efforts of Variety Village and the Rehabilitation Engineering Department at the Hugh MacMillan Medical Centre. The need was first identified by the staff at Variety Village, who, with their clients, contributed design input and tested and evaluated the guards. Design development and prototype construction has been carried out at Hugh MacMillan Medical Centre.

**Preliminary Results**—Sixty-eight amateur athletes were surveyed; thirty-seven in manual wheelchairs and thirty-one in electric wheelchairs. Only occasional minor injuries (bruises) have been experienced and/or observed by the players, despite frequent collisions. Concern over potential injury to themselves (including other parts of their bodies) was expressed by nineteen respondents. Game trials showed that the necessary shape of the guard caused some limitations in the player’s vision and movements. As well, the athletes indicated a general resistance to the imposition of more protective equipment in their game. This is consistent with the low incidence of injury and the lack of concern for injury by the majority of players. From the results, it was determined that the provision of a guard to provide physical protection is not necessary.

**Future Plans/Implications**—Future efforts should focus on the development of new equipment and games which have a low risk of injury inherent in them in order to encourage greater participation in wheelchair sports.

---

**Testing of Gel-Electrolyte Batteries for Wheelchairs**

**William E. Fisher, Ph.D.; Rob E. Garrett, B.Tech.; Barry R. Seeger, Ph.D.**
Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

**Sponsor:** None Listed

**Purpose**—The charge capacity of a liquid-electrolyte lead-acid battery can be determined by measuring the electrolyte density using a hydrometer, but this is not possible with gel-electrolyte batteries. Consequently, test equipment was needed to measure the charge capacity of gel-electrolyte batteries.

**Progress**—A simple test rig was developed to measure the capacity of the gel-electrolyte batteries used to power wheelchairs. It has been shown that discharge testing with a simple resistive load is a good indicator of battery performance when fitted to a wheelchair. Our battery tester comprises a resistive load, a timer, and a box housing the control switches and electronics. The system was designed to be simple to operate and suitable for use in a wheelchair maintenance workshop.

**Preliminary Results**—Results of 166 tests revealed a wide scatter of battery life with different users and also showed that, in many cases, the two batteries used in a wheelchair became unequal in charge capacity after some time in use. It is recommended that pairs of batteries should be charged in series to overcome this problem. A scientific paper describing the test rig and our results has been accepted by the *Journal of Rehabilitation Research and Development* for publication in Vol. 25(2), Spring, 1988.
B. Powered Controllers

UNISTIK Vehicle Controller: Safety, Reliability and Human Applications

Catherine W. Britell, M.D.
Spinal Cord Injury Service, Veterans Administration Medical Center, Seattle, WA 98108
Sponsor: VA Rehabilitation Research and Development Service

Purpose—A control system (the UNISTIK Vehicle Controller) has been designed to enable people with high quadriplegia and limited extremity function to drive a motor vehicle. In this study, engineering safety and reliability testing has been done on the system installed in a van. Engineering testing included lifetime testing of all servomechanisms and extended testing at elevated temperatures of the steering servomechanism. A flexible driver station for training and evaluation was developed and installed. Clinical evaluation of the van will be done in order to identify the types of disabled individuals who would benefit from the Controller and to create guidelines for evaluating and training prospective users of the Controller.

Progress—Engineering safety and reliability testing included lifetime testing of all servomechanisms and extended testing at elevated temperatures of the steering servomechanism. Following the tests, the servomechanisms were disassembled and checked for wear. Extensive road testing included simulated failures of van and controller subsystems. Clinical testing will consist of training 20 - 30 participants in the use of the system. Participants will be high-level quadriplegics, amputees, post-polio individuals, and individuals with cerebral palsy and muscular dystrophy. Training will include preliminary evaluations, in-vehicle instruction and on-road driving skills and will be done at the Seattle VAMC.

Preliminary Results—Results of engineering safety and reliability testing showed servomechanisms withstood lifetime and temperature testing. No excessive wear was found on gears or bearings in the servomechanisms. Simulated failures of van and controller subsystems produced predicted and reliable responses and proved the effectiveness of back-up systems for braking and steering.

Future Plans/Implications—The van will be clinically tested at the Seattle VAMC. Results from clinical testing and engineering safety and reliability testing will be incorporated into a production model of the UNISTIK Vehicle Controller system. Clinical testing will also identify who would benefit from the controller and define guidelines for training prospective users of the UNISTIK Vehicle Controller system.

Ultrasonic Head-Controlled Wheelchair and Interface

David L. Jaffe, M.S.E.
Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304
Sponsor: VA Rehabilitation Research and Development Center Core Funds; Paralyzed Veterans of America

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 wheelchairs in a socially acceptable and aesthetically pleasing manner.

Progress—In order to perform some tasks independently, severely disabled individuals must find communication pathways to replace the ones that have been totally lost or amplify the ones that are impaired. High-level quadriplegics have a particularly difficult time in replacing lost or diminished channels to the outside world since many of them can only control muscles at their neck level and above.

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 an 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 user’s head. 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 user’s current head position. A geometric relationship allows the offset from the base line and center line of the two sensors to be calculated. This information is then used to map the user’s head position onto a two-dimensional control space. 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.

The main advantage of this type of interface is that no mechanical contact between the sensors and the user’s head is required. This effectively separates the user from the device being controlled. With this unit, the user does not feel confined as with devices in close proximity to the face or body, as frequently occurs with other interfaces. He/she would therefore not feel “wired-up” using it; an important factor in its acceptance. The use of the remote sensing ability of the UHCI should result in rehabilitation devices that are socially acceptable and cosmetically pleasing.

Preliminary Results—UHCI have been installed on two electric wheelchairs. The first is an E&J model 3P equipped with a reclining Recaro seat and is in use in France by a quadriplegic woman. The second is mounted on an Invacare Rolls IV with a Solo Products Power Pack and is being evaluated by spinal cord injury patients at this facility.

Both units have been operational since June, 1983. User evaluation has been performed with ten 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 problems. Users stated that they preferred the ultrasonic head control to the chin-controlled joystick wheelchairs that 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.

A generalized interface for a robotics application has also been developed. As with the UHCI, the robot user will be able to select tasks and control the operation of a mobile robotic arm via head position. Specifically, the vehicle’s navigation path will be under the control of the user—its trajectory being “drawn” on a CRT with head motions.

A technical manual documenting the work on the UHCI, including background material, electronic schematics, computer program listings, explanations, and illustrations has been compiled. Its intended purpose is to provide information that would allow a technically knowledgeable and adequately equipped engineer to construct a duplicate UHCI and apply it to the control of devices such as powered wheelchairs. This manual has been made available to over fifty interested investigators around the world who are considering the UHCI for research or commercialization.

Future Plans/Implications—Within the VA, a Request for Evaluation has been submitted to the Evaluation Unit and approved. The funds for the production of four commercial prototype units have been received. A solicitation has also been published and a manufacturer is about to be selected from the responses. The delivery of the four units is expected one year after the award of the funds. These devices will then be evaluated at VA Medical Centers throughout the country. Finally, a decision will be made regarding the prescription of electric wheelchairs using the UHCI technology for appropriate severely disabled veterans.

Current Publications Resulting from This Research
A Study of Powered Wheelchair Controllers

Mark Hartridge, M.I.E. Aust.; Barry R. Seeger, Ph.D.
Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: Channel 10 Children’s Medical Research Foundation of S.A.

Purpose—The number of children using electric wheelchairs has increased rapidly. New types of wheelchair controllers permit alteration of the wheelchair response to user-input by limiting the wheelchair acceleration and by filtering the user’s input signals in various ways. However, the extent of driving improvements, if any, has not been objectively demonstrated. With the provision of independent adjustments for acceleration and signal filtering, a practical problem arises in determining which combination of settings will give the best wheelchair control for a particular user. On current commercial products, wide ranges of acceleration and filter settings are provided, as well as an adjustment for maximum speed. At present, we are unaware of any information which could assist in identifying combinations of settings likely to help the driving ability of various types of users. Such information would be valuable in assisting wheelchair users and therapists to optimize driving ability, and also in assisting manufacturers to improve the internal software of their controllers, thus providing more effective products for wheelchair users.

The aims of this study are: 1) to determine if new concepts in electronic wheelchair control are effective in improving wheelchair driving performance of children with cerebral palsy, and to quantify any improvements; and 2) to establish procedures for adjusting controllers 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.

The Development and Clinical Assessment of a Universal Wheelchair Controller System

M. Milner, Ph.D., P.Eng., C.C.E.
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: The Easter Seal Research Institute, Toronto, Canada

Purpose—This study has the following objectives: 1) to develop a closed-loop wheelchair controller that will respond to proportional and non-proportional interfaces; 2) to technically and clinically evaluate the performance of the prototype controller and the relative user driving response; and 3) to develop a manufacturing prototype of the controller and seek a manufacturer.

Progress—A unique wheelchair controller has been developed that can interchangeably respond to both proportional and digital control interfaces. This controller incorporates a motor speed control-loop which behaves in a fashion similar to cruise controls in modern automobiles and automatically compensates for environmental factors such as sidewalk slant, varying terrain and torque demands. For the clinician’s convenience, the input circuitry of the controller was designed in such a manner that it automatically recognizes the type of interface being connected to it and selects the appropriate decoding strategy. Rapid interchanging of interfaces is therefore possible for assessment purposes or as an individual’s physical condition deteriorates.

The back electromotive force (BEMF) generated by the permanent magnet motor, proportional to the angular velocity of the motor’s shaft, is used in closed-loop speed control circuit. An analogue error signal, proportional to the difference between the selected speed and the BEMF signal, modulates two bi-directional pulse train outputs in proportion to its amplitude and polarity. An analogue data selector is used to direct the modulator’s signals to the appropriate inputs of the MOSFET power bridge, and thereby derive the desired response from the motor.

A power MOSFET “H” bridge was developed to provide more efficient power switching to the
wheelchair motors when operated at 20 kHz. Closed loop dynamic and static braking circuitry was implemented in the design. Acceleration and deceleration rates are each independently adjusted via potentiometers.

Assessment Protocol for Prescription of Powered Mobility Devices

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8
Sponsor: The Hospital for Sick Children Foundation, Toronto, Canada

Purpose—This project studied predictors of successful powered mobility driving, with the goal of preparing an assessment protocol for the prescription of powered mobility devices. Currently, such a protocol does not exist. It appears that each prescribing Centre has a method of prescribing powered mobility devices which is based in part on the prescriber’s clinical experience, and in equal part on trial and error. The approach taken in this study was to first determine which, if any, measures predict powered mobility control, and then base an assessment on these predictors.

Progress—Fifty-seven subjects were seen in this study: twenty-four were able-bodied subjects, and thirty-three were disabled. All were subclassified into three age groups (i.e., 4-5, 6-7, and 8-9 years old).

Subjects were further classified according to physical ability level (i.e., able-bodied, walk-with-aid, walked into clinic, non-walker); according to experience with mobility devices (i.e., no experience, manual wheelchair, electric wheelchair, and passively mobile); and, according to diagnosis (cerebral palsy, diplegic and quadriplegic involvement, spastic and athetoid, spina bifida, spinal muscular atrophy, hemiparesis, and one subject each with quadrilateral amputations and head injury).

A large battery of standardized motor, perceptual, and intelligence tests was administered, including: Motor: Peabody Motor Development Scale; Perceptual: Motor Free Perceptual Test and Ayers Space Visualization Test; Intelligence: WISC-R or WIPPSI MAZES; Raven Colored Progressive Matrices; Peabody Picture Vocabulary Tests; WISC-R Picture Completion Subtest; WISC-R Picture Arrangement Subtest; Representative Stencil Design Test; Vision Examination: carried out with 30 percent of the disabled subjects.

All tests in this battery were administered and scored in the standard way. In addition to this test battery, four computer-based pre-driving tests, two computer-simulated driving tests and two actual driving tests (wheelchair and remote-controlled driving tests) were performed by the students. Pre-driving tests consisted of a targeting test, a tracking test, a test of dynamic perception and a simple maze. All driving tests (simulated and actual) use the same five courses which were to be traversed in one of two speeds. These courses consisted of: 1) straight-away; 2) S-curve; 3) sharp (90 degree) left turn; 4) backing up and sharp left turn; and 5) two sharp right turns. For simulations and remote-controlled driving tests the courses were scaled to the size and speed of the moving object.

Preliminary Results—Data collection was completed during the summer and data coding and analysis was commenced. All data processing is being carried out using SYSTAT (version 2.1). Analysis steps to be completed are: a) comparisons of means by subject groups and age groups; b) testing of regression models for each of the test domains (motor, perceptual, spatial, verbal, pre-driving, simulation and remote); c) selection of predictors by test domain and subject (ability) group.

Publications Resulting from This Research

A "Smart" Controller for Electric Wheelchairs

Ian R. Loudon and Paul Nisbet
Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED Scotland

Sponsor: Lothian Health Board, Scottish Education Department

Purpose—The aim of this study is to produce an adaptable and programmable controller which can be used with a standard electrically-powered wheelchair so as to allow the severely disabled user a degree of independent mobility. The controller will also operate as a simple communication device which will enable the same switches to be used for both functions, thereby simplifying the learning process and providing greater incentive for the development of control skills.

Progress—We have produced two prototype controllers which are based on the Rockwell R65F12 microprocessor and which are programmed in Forth. The controller is capable of monitoring bump detectors, proximity sensors, wheel position sensors, a line follower and several user inputs. The input devices include single and double switches, switched and analogue joysticks and direct input from portable computers or communication aids.

The control software is written in Forth and is currently under development. It is based on a queued data structure and uses a modular program construction. By connecting the controller to an external computer, the appropriate operating mode can be selected to suit the individual needs of the user.

The degree of assistance which the controller provides varies from following a preprogrammed course to a completely user-controlled mode. The speed and acceleration of the chair can be limited where appropriate and a number of experimental control systems involving feedback to the user by special joysticks are being investigated.

The safety of users with limited control abilities has been enhanced by the incorporation of bump and proximity detectors which slow the chair down as it approaches obstacles and stop it in the event of collision. Other sensors keep the chair moving in a straight line on uneven surfaces or allow it to follow a path marked on the ground.

Future Plans/Implications—Trials will begin soon with a group of wheelchair users who have no means of controlling their chairs at present. This group covers a broad spectrum of physical and mental handicaps with several multiply-handicapped subjects. A variety of control schemes based on the principles of external physiological proprioception (developed by the Bioengineering Centre while investigating the control of arm prostheses) will be adapted to wheelchair control by means of specially-produced joysticks. This work should improve the quality of control for all joystick users.

C. Seating Systems

Seat Cushions for the Paralyzed

Bok Y. Lee, M.D. and Leon Bennett, M.A.E.
Veterans Administration Medical Center, Castle Point, NY 12511 and Veterans Administration Medical Center, New York, NY 10001

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to evaluate the role of shear in pressure sore causation, to assess cutaneous buttocks blood flow of paraplegic subjects with respect to pressure sore trauma, and develop an instrument capable of sensing buttocks blood flow for clinical prescription purposes.

Progress—Thirty-four paraplegic subjects have been
evaluated employing standard segmental Doppler ultrasound techniques, as used in the assessment of occlusive arterial disease, and also local cutaneous blood flow in the region of the ischial tuberosities while seated, as given by harmonic analysis of photoplethysmographic pulsatile waveform. The correlation is sought between known pressure sore trauma, as determined from a subject's medical records over a prior 5-year period, and the various blood flow measurements.

Serving as a control group, 23 normal subjects have also been tested while sitting, yielding data on blood flow, pressure, and shear.

Preliminary Results—To test the hypothesis that repeated pressure sores in a given paraplegic subject may be simply the result of pure chance, a Poisson distribution has been constructed, employing the average possibility of an initial pressure sore onset, as evidenced by the subject pool (50 percent). The results suggest that chance is unlikely to explain the distribution of multiple pressure sores: approximately 5 times as many subjects develop 3 or more pressure sores over the test period as may be expected to arise through chance. It follows that there is reason to seek a physical cause for at least those subjects exhibiting multiple pressure sores.

Analysis of paraplegic ankle pressure testing (ankle/brachial) data, when plotted against the frequency of pressure sore occurrence, does suggest that there is some connection between these events. That is, a least squares regression, based on a straight-line relationship, indicates the likelihood of multiple pressure sores to increase as ankle pressure decreases, implying a connection between multiple pressure sores and an impaired peripheral arterial circulation. However, the level of significance \( P = 0.08 \) is low, implying considerable scatter in the results and a lack of specificity of application.

Testing for local buttocks circulation characteristics via photoplethysmographic harmonic analysis, and also plotting against the frequency of pressure sore occurrence, yields a similar qualitative trend: the more impaired the circulation, the greater the number of pressure sores. However, with this experimental procedure, the quantitative aspects are improved; the level of significance \( P = 0.008 \) may be regarded as highly significant. In summary, our results strongly imply a connection between local buttocks cutaneous flow and multiple pressure sore occurrence.

Results concerning vertical shear effects upon animal pressure sore threshold experimentation indicate that those tests conducted with small pistons impart much of the test load in the form of vertical shear, rather than pressure. Computations have been prepared to illustrate the extent of the misassigned load, as a function of piston diameter.

Future Plans—Additional measurements of circulation are to be assessed for pressure sore association and all results will be incorporated into a technical manuscript.

A Comparative Evaluation of Special Seating for Severely Disabled Children

William E. Fisher, Ph.D., and Barry R. Seeger, Ph.D.
Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: Channel 10 Children's Medical Research Foundation of S.A.

Purpose—In recent years a number of special seating systems have become commercially available, and this study was undertaken in order to compare special seating systems for use in Australia.

Progress—The subjects for this study were eight children with cerebral palsy or traumatic brain damage, who were selected because they required more contoured seating than padded flat surfaces. The categories of cerebral palsy involvement and seating options defined by Hobson and Trefler (1984) were used to define appropriate seating types.

We purchased a Pin Dot Modular System, a Canadian Posture and Seating Center Modular System, a Matrix Body Support System, a Medical Engineering Resource Unit Matrix, a Canadian Posture and Seating Center Foam-in-Place System, and we also included a Hexcelite seat and a Foam-and-Ply seat.
Results—A very satisfactory result was obtained with each seating system. They all rated very highly in terms of both comfort and appearance, and the attainment of functional goals was dependent on the initial setting of achievable goals regardless of the seating system chosen. The most dramatic differences between seating systems were in terms of cost, with the Pin Dot Modular being the most expensive, followed by the CPSC Modular, MERU Matrix, Matrix Body Support, CPSC Foam-in-Place, Hexcelite, and Foam-and-Ply being the least expensive. Other comments were that the Pin Dot Modular looks very good, the CPSC Modular is easy to clean, the MERU Matrix and the Matrix Body Support System are easily adjusted, the Hexcelite System allows good ventilation and the Foam-and-Ply seat is highly versatile.

Publications Resulting from This Research


Computer-Aided Prescription of Specialized Seats for Wheelchairs

Steven I. Reger, Ph.D.; Donald Neth, M.S.; Thomas McGovern, M.S.
Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106
Sponsor: The Cleveland Clinic Foundation Research Institute

**Purpose**—This project will develop and evaluate the computer-aided measurement and prescription of wheelchair seating supports. The scope of the proposed project does not include computer-aided manufacture of the personal body support: the focus is on the accuracy and validity of the computer-aided measurement and prescription processes.

A new concept in clinical data collection is proposed through the use of a computer-aided prescription seat (CAP-seat). The design will allow passive measurement of posture, pressure, and body contours. For the measurements, the patient will be positioned in a subjectively established sitting posture. Interactive adjustments will be carried out under operator control using the pressure and contour information provided by the instruments. The prototype fitting seat (prescription seat) will be evaluated with children and adult disability groups selected from the clinical load of the Cleveland Clinic Foundation. Postural and support data will be transferred through a telephone modem to a central location, removed from the sites of patient evaluation and fitting, for computer-aided manufacturing of seat and supports.

**Progress**—Two sets of an 8-by-8 array of contour gauges have been built and mounted on the back and seat of the chair for the determination of back and buttocks contour. The software used in the rapid collection of data from the fitting seat has been developed and debugged on the IBM AT, using Pascal programming language. The software has been interfaced with the I/O hardware, including an A/D board and a parallel I/O board. The contour gauges have also been interfaced and test data have been gathered. A software routine which transforms the data points into contours has been written. These contours can be viewed on the computer screen or they can be output to the graphic plotter.

**Future Plans/Implications**—Actual shape adjustments will be made by an array of low-pressure pneumatic cylinders acting under operator control to deform the support surface while the subject is sitting on it. Work is currently progressing on the computer interface to the pneumatic cylinders.
Weightbearing Characteristics of Soft Tissues for Body Support Applications

Steven I. Reger, Ph.D.; George H. Belhobek, M.D.; Thomas McGovern, M.S.
Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106
Sponsor: The Cleveland Clinic Foundation Research Institute

Purpose—All materials used in orthopaedics for body support carry the risk of causing soft-tissue trauma because of the load transfer at the interface. However, an objective assessment of the support materials for individual need has not been developed. The efficacy of the load transfer from the support cushion to the tissues is limited by the stiffness of the structures carrying the load. For equal loads, a difference in stiffness results in higher deformation of the lower-stiffness component, which leads to shear loads and hammocking at the soft-tissue interface.

The purpose of this work is to obtain a preliminary comparison of the vertical spring characteristics (stiffness) of the composite soft tissues (muscle, fat, skin) near bony prominences versus the vertical spring characteristics of common foam support cushions.

Results—Thicker tissues were observed in the normal subjects, leading to the conclusion that higher pressure gradients must exist in the paraplegic tissues than in the normal. Bony prominences in the paraplegic tissues “bottomed out” under body weight alone, increasing the risk of tissue trauma. The stiffness of the Durafoam cushion showed a reasonable match to the spring constant of the paraplegic trochanteric area. The performance of other (viscoelastic) foam tested did not match the mechanical properties of the soft tissue areas.

Toward Further Development of a Seating System for the Physically Handicapped

W. Lotto, M.D., F.R.C.S.(C), F.A.C.S. and M. Milner, Ph.D., P.Eng., C.C.E.
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8
Sponsor: Easter Seal Research Institute, Toronto, Canada

Purpose—The aim of this project is to develop a modular seating system to meet the postural support needs of children with cerebral palsy. The specific goals of the study are twofold: 1) to design and develop a cost-effective modular seating system to meet the postural support needs of children with cerebral palsy; and 2) to assess the performance of the two types of modular seating systems fabricated.

Progress—A review of seat inserts dispensed at the Centre demonstrates that a large percentage of children with cerebral palsy have common postural support requirements. It is intended that this population be fitted with a cost-effective modular seating system.

A tubular steel frame was designed to hold the seat and back components of the seating system. Commercially available modular seat and back cushions were purchased and secured to the frame by independent vacuum-formed ABS pans. An adjustable headrest and polyester restraint straps for the trunk and pelvis were also secured to these pans.

Two types of frames were designed: the first type, intended for mildly-involved children, is the “fixed” frame. The angle at which the entire frame is attached to the wheelchair is fixed at assembly. The
second type of frame, intended for moderately-involved children, is the "tilting" frame. While fixed to the mobility base, the entire frame is adjustable to any angle from the upright position back to a 40 degree inclination. The angle between the seat and back remains constant. Both types of frames have adjustable telescoping tubes to allow for growth of the child. Also, both frames have flush bases to permit them to be positioned on a chair when removed from the mobility base.

Preliminary Results—Two of each type of the systems have been dispensed as part of the study. The results of clinical and technical evaluations were made available in 1987.

Comparison of Pressure Monitoring Systems

Thomas McGovern, M.S.; Sandy Magnano, R.N.; Thomas P. Stewart, Ph.D.; Steven I. Reger, Ph.D.
Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106 and Gaymar Industries, Inc., Orchard Centre Industrial Park, Orchard Park, NY 14127

Sponsor: The Cleveland Clinic Foundation Research Institute

Purpose—The importance of pressure evaluation in clinical assessment of body-support systems is now clearly recognized and used in many progressive hospitals and rehabilitation institutions. However, the transducers used in pressure evaluation are inconsistent, and the measurement technology is poorly defined and varies among the institutions.

Factors affecting the results of pressure evaluation are many, but the important ones are: 1) the transducer size and material; 2) load shape and its interaction with the support material; 3) the method of endpoint detection; and, 4) the uniformity of the measurement technique.

The objective of the work was to establish agreement among the three most common pressure-evaluating systems, using a clinically acceptable protocol. These results may subsequently serve to develop correction factors for shape, size, and material variations among transducers.

Progress—Interface pressures were measured by the Scimedic, TIRR, and Gaymar pressure transducers on 10 normal volunteers by two experienced independent observers. The subjects were tested in the sitting and recumbent positions, using all three transducers on three support systems successively. In the sitting position, the pressure was measured under the coccyx, ischial tuberosities, and trochanters. In the lying positions, the trochanteric and sacral pressures were observed. All measurements were repeated three times by each observer, relocating the transducers each time. All pressure values were recorded, but only the highest of each three observations was used for the statistical analysis.

The support materials were blue "egg crate" foam (EC), high resiliency 3-inch-thick polyurethane foam (HR), and the constant-pressure "Sof-care" air inflation system (SC). The support materials were made into seat-cushion and bed-cushion size pads for the measurement of contact pressures. Recumbent pressures on the egg crate foam were measured on both single and double layers, but sitting pressures were measured only on double layers of this foam.

Results—Interface pressures were measured up to 100 mmHg to minimize hysteresis effects in the vinyl transducer bags. The lower limit of the measurements was set by the Scimedc transducer, which did not provide readings less than 20 mmHg.

Linear regression analysis was performed on data collected at the Cleveland Clinic, at Gaymar Industries, and on the combined data from both locations. At each location, pressure values collected from 10 subjects using one instrument were regressed on values measured on the same 10 subjects with a second instrument. For the combined data, the regression was repeated using all 20 subjects.

All transducers tested behaved reliably and correlated well to a significant degree. When the measured pressure distributions were examined for correlations among transducers, the standard deviations were 10-to-15 mmHg. The standard deviations among cushion types, however, were in the range of 14-to-21 mmHg. This indicates more variance among cushions using the same transducer at the same anatomic location than among transducers on the same cushion at the same anatomic location.
Wheelchairs and Powered Vehicles

Wheeled Mobility and Improved Seating Systems

Warren G. Stamp, M.D. and Clifford E. Brubaker, Ph.D.
Department of Orthopedic Surgery and Rehabilitation, University of Virginia Medical Center, Charlottesville, VA 22908; and University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

Sponsor: National Institute on Disability and Rehabilitation Research; Rehabilitation Engineering Center Program

Purpose—The University of Virginia Rehabilitation Engineering Center (REC) is in the fifth year of a 5-year program for research and development on wheelchairs and seating for the disabled. A part of the work on seating has been conducted in collaboration with the University of Tennessee Rehabilitation Engineering Program at Memphis under contract.

The emphasis at the REC is to conduct technical studies on all aspects of wheelchair and seating design and function that will lead to a better understanding of the principles involved, and therefore, contribute to improved design, fabrication, and prescription of wheelchairs and seating.

Progress—The REC has conducted some 23 tasks grouped under 5 areas. The work accomplished in each of these areas during the current period is presented as follows:

Ergonomics: Propulsion efficacy was evaluated at multiple work intensities for hand-rim and lever propulsion in treadmill and dynamometer simulation, and for hand-rim, lever, and "poling" under real conditions. Further model development was carried out for optimization of wheelchair propulsion efficiency. Upper-extremity motion was evaluated with respect to variation in position over a three-dimensional array and at various work intensities.

Analysis and Design of Structural Components and Systems: Work has continued on the double-drum fatigue tester (which was adopted as the ISO standard test device) to investigate the efficacy of different attachment procedures and to determine the appropriate configuration and number of cycles for the test standard. Work has been completed on the development of equations to describe the dynamic behavior of castored mobility devices as a function of load, speed, and perturbing forces. Structural analyses have been conducted on two lightweight commercially available wheelchairs, including finite element analysis. A PC-based finite-

...element analysis program for wheelchair frames has been completed and is being distributed at nominal cost.

Seating and Body Support: The anthropometric data base, which includes 80 variables relevant to specialized seating, has been expanded for cerebral palsy (CP) and spinal cord injury (SCI) populations. Work has continued to determine the effects of variation in position on spasticity in CP children. Comparisons were made for different cushions to determine compression, shear and surface tension characteristics. An evaluation was made of differences in pressure distribution at the seat interface for flat and custom-contoured cushions of different density foams. Comparisons were made for pressure distribution of commercially available cushions among populations of paraplegics (both spastic and flaccid) and quadriplegics.

Electromechanical Propulsion: A patent application has been filed for a contained-electrolyte process that could result in a significant cost reduction in the manufacture of extended-life batteries. A battery charger control algorithm has been developed and tested that predicts the optimum time to stop the charging process. Work has continued on development of fault-detection capability for powered wheelchair components.

Product Design and Development: The UVA lever drive has been redesigned as an add-on unit. It has been successfully attached to commercially available lightweight wheelchairs. The compact user-adjustable wheelchair has been redesigned to reduce weight and fold more compactly. Dynamic brakes have been designed and fitted to commercially available wheelchairs: these provide control on slopes or at high speed. They also function as parking brakes. A computer-aided manufacture (CAM) system for carving custom seat cushions is near completion. This system utilizes data obtained from measurement of client surface contours to produce the three-dimensional seating surface.