Using robotics and virtual reality to improve functional status

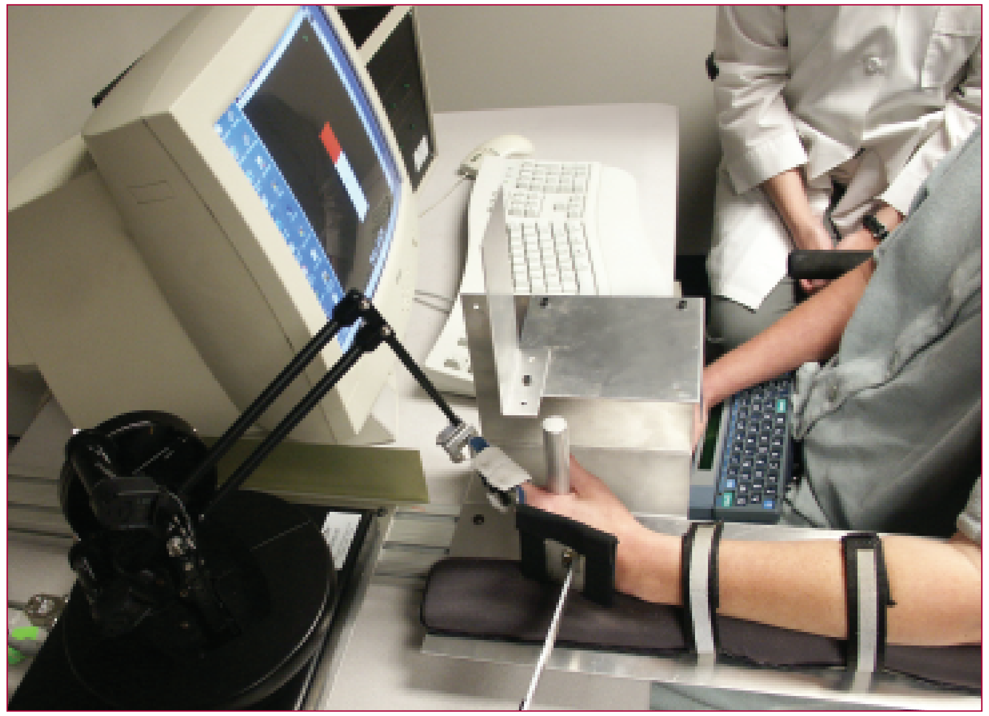
Impairment of controlled body movement is one possible result of traumatic brain injury (TBI) or stroke, often causing a decline in functional capacity that may decrease the person's sense of well being. Motor dyscontrol often outlives the recovery of some elements of extremity function. Moreover, brain injury itself tends to produce a discrepancy between real and perceived ability. This disparity has been implicated as a hindrance to the recovery of motor skills.

Therapies to improve functional capacity have met with inconsistent levels of success, and the resources required for these interventions are substantial. An approach that could provide goal-directed sensorimotor feedback might offer unique advantages. Robotic intervention is well suited for this task.

Studies have shown that primates with upper-extremity impairment can regain functional skills using robotic devices. The ideal technique would enable precise recordings of movements as force is applied to an affected limb. Compared to patients receiving human-assisted therapy, those using a robotic technique experience no decrease in range of motion and no increase in pain, while improvements in strength and mobility often match or exceed the gains achieved with human-assisted therapy.

A key shortcoming of currently available robotic systems is that none uses perceptual manipulation. As part of our National Institute on Disability and Rehabilitation Research (NIDRR) TBI Model System center grant, we designed and developed a robotic rehabilitation environment. We determined the extent of perceptual gap required to create an optimal level of distortion for the therapeutic environment: In a series of experiments conducted with unimpaired subjects, ages 18 to 35, we identified the just-noticeable difference in the amount of force applied to the index finger and in the degree of change in the finger's position. In this cohort, the threshold of detection was 18% for applied force and 14% for position change.

We also tested the subjects' threshold for detecting distortion in a virtual environment. In this setting, participants failed to distinguish distortions up to 36%. We are beginning to recruit from clinical populations for the next phase of this project.



▲ The above photo is a demonstration of the robot-assisted perceptual manipulation system. The robotic device on this person's left index finger allows for precise recording of movements and application of precise levels of force. The computer display provides "distorted" perceptual feedback, the resulting effect of which is to functionally increase the individual's range of motion beyond their own initial estimate.

CONTINUING EDUCATION

In conjunction with the University of Pittsburgh's Center for Continuing Education in the Health Sciences, the Department of Physical Medicine and Rehabilitation will hold its 15th Annual Electromyography Course March 24 and 25, 2005, in Pittsburgh. Up to 12.0 Category-1 CE credits may be earned. For more information, contact Judy Scheeser at 412-648-6654.

For more information about our clinical services or for assistance with patient referrals, please call UPMC MedCall at 412-647-7000 or 1-800-544-2500.

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REHAB PROGRESS

News from the University of Pittsburgh Department of Rehabilitation and Physical Medicine Fall 2004

Inside This Issue

From the Chairman's Desk

In the nearly five years since accepting the chairmanship of the Department of Physical Medicine and Rehabilitation at the University of Pittsburgh, I have seen remarkable progress in the department. This issue of *Rehab Progress* highlights a few indications of the department's growth.

The University of Pittsburgh and the University of Pittsburgh Medical Center (UPMC) have contributed more than $20 million to the development of a rehabilitation network, providing clinical services in a catchment area that extends across three states. The department provides rehabilitative services for disabling conditions affecting a full range of clinical populations. Our particular strengths are musculoskeletal medicine and rehabilitation for patients with spinal cord or traumatic brain injuries.

UPMC, a designated Level I Regional Resource Trauma Center — the busiest in Pennsylvania — has built a rehabilitation network of more than 200 beds, supported by six rehabilitation units and a freestanding rehabilitation hospital. These resources — and our exceptional faculty — position us as a leader in the field of clinical rehabilitative services and in basic and clinical research.

The university consistently ranks in the top 10 among institutions funded by the National Institutes of Health (NIH). Our own department now ranks eighth in NIH funding among academic departments of Physical Medicine and Rehabilitation. We have also received numerous federal research grants from the Centers for Disease Control and Prevention; the VA Rehabilitation Research and Development Center; and the National Institute on Disability and Rehabilitation Research (NIDRR). Ours is one of only seven PM&R programs with NIDRR-sponsored model systems center grants for spinal cord injury and traumatic brain injury, and we have developed a Musculoskeletal and Acupuncture Research Center that is unique in the region and nationally.

A small sample of the department's research in basic science includes investigations in genetic predictors of response to rehabilitation; the roles of various transmitter systems in recovery; and hormonal mediators of response to injury and treatment.

Through collaborative relationships with Carnegie Mellon University and the Human Engineering Research Laboratory (co-sponsored by the VA Rehabilitation Research and Development Center), our faculty members can pursue cutting-edge, technology-based areas of research, including studies in wheelchair design and ergonomics; the use of virtual reality and robotics in upper-extremity rehabilitation; the application of telemedicine technologies to case management; functional neuroimaging in rehabilitation; and wheeled mobility and wheelchair transportation safety, undertaken as part of an NIDRR-funded Rehabilitation Engineering Research Center (RERC).

The following pages feature brief summaries of a few of our research studies that may be of interest to you.

If you are ever in Pittsburgh, I would be happy to show you our facilities or talk with you further about our clinical and research programs. If you wish to discuss any aspect of our program, please call me directly at 412-648-6979. I would be delighted to speak with you.

Sincerely,

Ross D. Zafonte, DO
Chairman,
Department of Physical Medicine and Rehabilitation
University of Pittsburgh

Gender differences in traumatic brain injury pathophysiology

Studies show conflicting evidence of gender differences in pathophysiology and outcomes following traumatic brain injury (TBI), with generally less favorable one-year outcomes and greater disability in women than in men following brain injuries of equal magnitude. Although these clinical observations were confirmed by the work of UPMC physiatrist Amy Wagner, MD, several animal studies have shown that female hormones attenuate excitotoxicity, ischemia, and oxidative stress — which produce secondary injury after TBI.

Using the University of Pittsburgh's NIH-funded Brain Trauma Research Center database, we completed a retrospective clinical study to assess gender differences in cerebrospinal fluid (CSF) markers of traumatic brain injury and to determine if hypothermia affects these markers in a gender-specific manner. Multivariate regression modeling demonstrated gender differences in the production and time course of a CSF marker of excitotoxic injury and an early postinjury marker of ischemia. Female hormones appear to offer some level of neuroprotection against excitotoxic and ischemic injury. With hypothermia, however, the same study showed evidence of reduced excitotoxic injury, primarily in men. This finding may be due to an apparent "floor effect" in reducing excitotoxic injury with hypothermia in women.

Ischemic injury and excitotoxicity were also linked to a marker of oxidative stress. Again there were significant gender differences in the relationship of ischemia/oxidative stress and excitotoxicity/oxidative stress. For a given excitotoxic or ischemic insult, women have much lower oxidative stress loads than do men, suggesting that there may be acute clinical correlates to the early neuroprotection reported in studies on experimental brain trauma.

Dr. Wagner recently received funding through a competitive award for renewal of a CDC center grant: the Center for Injury Research and Control. This grant focuses on the role of sex hormones in mediating gender differences in CSF markers of TBI and evaluating the role of acute and chronic hormone levels on neuropsychological and functional outcome and quality of life.

The full article may be read in Wagner AK, Bayir H, Ren D, Puccio A, Zafonte RD, Kochanek P (2004) "Relationships between cerebrospinal fluid markers of excitotoxicity, ischemia, and oxidative stress after severe TBI: The impact of gender, age, and hypothermia." *J Neurotrauma* 21:125–36.

Enhancing access to services after brain injury

Traumatic brain injury (TBI) poses significant and enduring problems for both survivors and caregivers. Chronic problems often require people with TBI to be institutionalized in order to provide a safe environment and 24-hour supervision. For the family member who assumes the role of primary caregiver, the constant demands of meeting the patient's need for supervision and care exact substantial economic, emotional, and social costs. Families often encounter difficulties in identifying and accessing available resources.

To address a new priority of the National Institute on Disability and Rehabilitation Research (NIDRR) that encourages research to evaluate the impact of innovations in service delivery on TBI patients, we developed the Virtual Case Manager (VCM). This project employs state-of-the-art, Internet-based technology to enhance service support and delivery for TBI patients and their families. Focusing on the needs of people with TBI and their family caregivers, the VCM provides users with a guide to educational resources and a framework to receive answers to their questions and concerns. It is designed to enhance utilization of health care and community services. A website has been created specifically for in-home installation and to assist patients with TBI and their caregivers in daily living.

Additional information is available at www.umc.pitt.edu/tbi/professionals/vcm.html.

Body vibration in wheelchair users: Can select seat cushions and back supports make a difference?

In a recent study, we examined whether selected wheelchair seat cushions and back supports minimize the transmission of vibrations, which may increase the risk for secondary injury (*e.g.*, low-back pain) among people who use wheelchairs.

We examined 32 wheelchair users on an activities-of-daily-living wheelchair course at three different times using 16 randomly selected seating systems (*i.e.*, a cushion and back support) as well as the subject's own preferred seating system. Vibration data were collected using accelerometers positioned at the seat and at the participant's head. We calculated weighted fore-to-aft, vertical, and resultant transmissibility values based on the vibrational-dose value in order to determine if differences exist among the seat cushions and back supports while traversing different obstacles.

Significant differences in vibration between seat cushions were not observed when all of the obstacles were combined. However, we did detect significant differences in vibration with different back supports when participants traversed curb descents, dimple strips, or rumble strips. No single seat cushion or back support unequivocally produced either the best or the worst results. This observation may be explained by the diversity of physical characteristics in those with disabilities, and suggests the possibility that individual wheelchair users could be biased in favor of the seating system most similar to individual body build.

The full article may be read in DiGiovine CP, Cooper R, Fitzgerald SG, Boninger ML, Wolf EJ, Guo S (2003) "Whole body vibration during manual wheelchair propulsion with selected seat cushions and back supports." *IEEE Trans Neural Syst Rehabil Eng* 11:311–22.

Improving community mobility

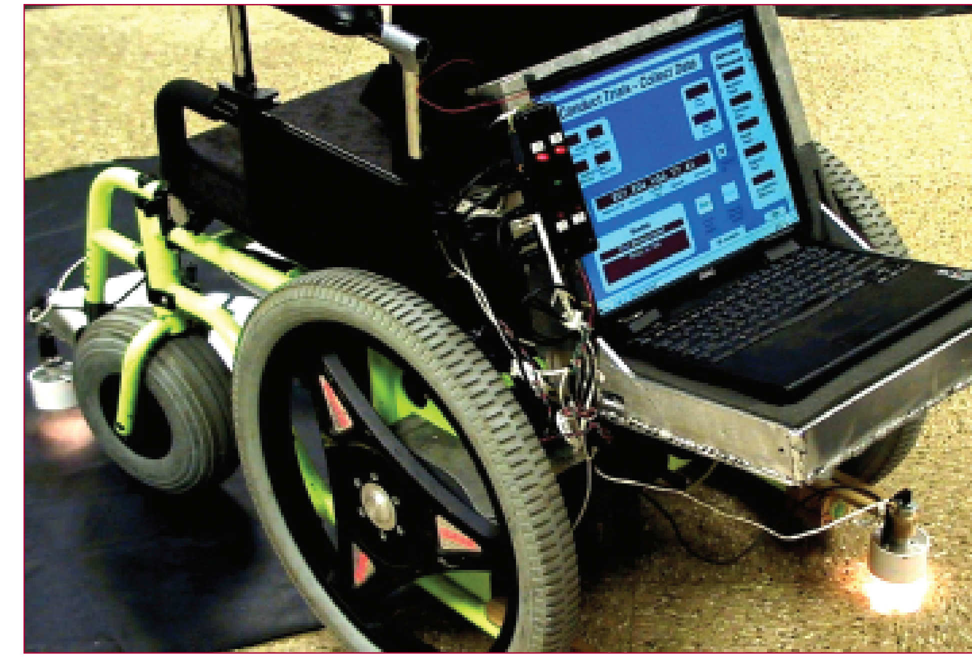
The ability of an adult to drive an electric-powered wheelchair (EPW) — functionally and without supervision in a variety of environments — after an event that results in severe physical disability is a critical determinant of employability, social access, and self-esteem.

The joystick has been the standard device for providing EPW control to a person with a disability. Conventional movement-sensing joysticks allow many people to make use of EPWs, but some patients with brain injury lack the functional motor skills necessary to operate standard joystick controls. In people with residual effects of brain injury, such as tremor, spasticity, weakness, and attention deficits, safe operation of conventional EPWs is difficult or impossible.

To assess a person's ability to drive a wheelchair, we recently developed, and are currently testing, a novel control system that combines a programmable force-sensing joystick with a head-position monitor that can be customized to address the individual user's motor and perceptual deficits. The subject first navigates through a virtual environment while observations are made of the performance time and the number of times that the virtual wheelchair deviates from the correct path.

During the second phase, the participant operates the wheelchair in surroundings that replicate real-world mobility challenges, such as maneuvering around furniture and bathroom fixtures, driving across carpet and pavement, and negotiating curb cuts and ramps (both up and down). By using this novel combination of technologies, we anticipate improving wheelchair safety and community mobility for those with brain injury.

Additional information is available at www.umc.pitt.edu/tbi/professionals/persmob.html



▲ On-board data collection system for the personal powered mobility study

Dopamine kinetics and TBI

Altered dopamine (DA) neurotransmission is hypothesized to play a role in neurobehavioral deficits after traumatic brain injury (TBI). In the clinical setting, DA agonists have been shown to improve aspects of mental functioning after TBI, and multiple animal studies document their capacity to improve behavioral performance.

We recently demonstrated chronic post-TBI reductions in striatal dopamine transporter (DAT) protein and increases in tyrosine hydroxylase (TH), two proteins that are critical in the release and reuptake of DA. However, the effects of these changes in DAT and TH level on DA neurotransmission remain unknown.

The goal of this project was to assess striatal DA neurotransmission by evaluating presynaptic striatal DA kinetics in conjunction with neuroprotein and neurobehavioral correlates after experimental traumatic brain injury. We evaluated electrically evoked DA release and DA clearance kinetics two weeks after injury using fast scan cyclic voltammetry (FSCV), which permits real-time, in vivo evaluation of dopaminergic kinetics.

We monitored striatal dopamine release during bilateral electrical stimulation of the medial forebrain bundle in anesthetized rats using FSCV in conjunction with Nafion-coated carbon fiber microelectrodes. We also evaluated rotational behavior prior to FSCV. After FSCV, we evaluated a variety of striatal DA markers, including DAT, TH, dopamine type-2 receptors (DRD2), and vesicular monoamine transporter (VMAT). Our results showed lower striatal evoked overflow of DA in injured rats than in controls. We also showed significant differences in zero- and first-order DA clearance for injured animals, as well as an increase in DAT efficiency after TBI. Decreases in DAT expression were noted post-injury, with no change in VMAT expression, indicating a regulatory alteration in the concentration of DAT.

Behavioral data in this injury model suggested a low incidence of rotational behavior, and the data correlated well with bilateral changes in presynaptic kinetics and DA-marker expression. The post-TBI increases in DAT efficiency observed in this study provide one explanation for the potential efficacy of DAT inhibitors (DA agonists) to improve cognitive recovery. Future work will evaluate the effects of DA agonists on striatal neurotransmission.

Sokoloski JE, Ren D, Ma X, Khan A, Zafonte RD, Dixon CE, Wagner AK (2003) "In vivo electrochemical and neurobehavioral analysis of striatal dopamine neurotransmission after experimental traumatic brain injury." *J Neurotrauma* 20:1121.