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REHAB PROGRESS

News from the UPMC Institute for Rehabilitation and Research Winter 2005

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Ross D. Zafonte, DO

Monkey see – Monkey do

Neural prosthesis lets monkey feed itself using brain only

In a major advance that could lead to an evolutionary leap in prosthetic devices for people who have suffered limb amputation or spinal cord injury, researchers at the University of Pittsburgh have demonstrated that a monkey can feed itself without lifting a finger, simply by using a robotic arm directed by signals from its brain.

The device, about the size of a child's arm, is a neural prosthesis with a fully mobile shoulder and elbow and a simple gripping appendage that allows the monkey to grasp food while its own upper extremities are restrained. Wired via electrodes attached to probes that tap into neuronal pathways in the motor cortex, the prosthesis intercepts signals responsible for voluntary movement. The neurons' collective activity is fed through an algorithm developed at the University of Pittsburgh and sent to the robotic arm to direct its movement.

Results were presented in San Diego during the 2004 Annual Meeting of the Society for Neuroscience. Senior researcher on the project is professor of neurobiology Andrew Schwartz, PhD, of the UPMC Institute for Rehabilitation and Research.

For each voluntary movement, neurons in the primary motor cortex change their firing rate, and the activity from many neurons is routed through the spinal cord to various muscle groups to initiate movement.

Since many thousands of neurons must fire in concert to allow even the simplest movement, it would be impossible to tap into all of them. The researchers developed an algorithm to fill in the missing neuronal signals, which allowed production of a useable signal from a manageable number of electrodes.

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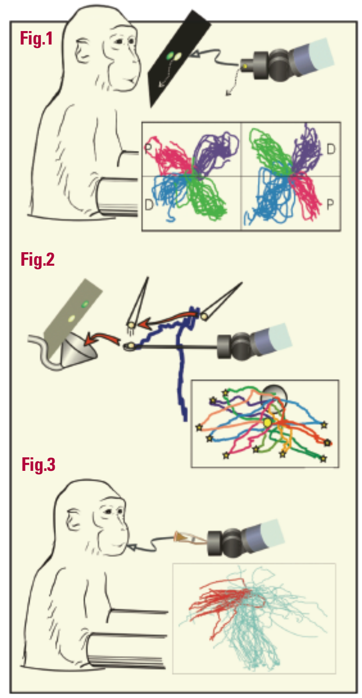


The subject was first trained to control a computer cursor in a 3D virtual environment (VE). The monkey used both manual and cortical control to move the cursor in a center➔out pattern to reach targets positioned at the eight corners of a virtual "cube" that was visible in the subject's workspace.

Fig. 1. Working in the same VE, the subject uses direct cortical control to instruct the robotic arm to trace the 3D center➔out trajectories. The robotic arm is not visible to the monkey. Inset: robot trajectories for the task, as viewed from the monkey's perspective. P = proximal, D = distal.

Fig. 2. Using the same VE, the subject retrieves food items from arbitrary locations. The blue trace shows the path of the robot while "pursuing" a moving food item. Inset: movements from the home position (yellow circle) to food items (stars) and back to the hopper, which delivers food to the monkey's mouth.

Fig. 3. Delivering food to the mouth using a cortically controlled robotic arm. With the VE display removed, the subject can see the robotic arm, and the piece of orange clipped into the end-effector of the arm. Inset: 10 minutes of cortical control trajectories from a central "start" location. Red traces show cortical control when an orange piece is in the robot.

Source: Helms Tillery SI, Taylor DM, Schwartz AB. The general utility of a neuroprosthetic device under direct cortical control. *Proc Eng Med Biol Soc 25th Int Conf.* 2003; 2043–6.

Monkey-*contined*

The algorithm that they developed to decode the cortical signals acts like a voting machine, by using each cell's preferred direction as a label and taking a continuous tally of the population throughout the intended movement. In order to fine-tune the algorithm, the monkey was first trained to reach for targets, electrodes were (painlessly) placed in the cortex, and the upper extremities were restrained. Under the assumption that the animal's intention was to reach for targets, the researchers then adjusted the algorithm.

According to Chance Spalding, a bioengineering graduate student in Dr. Schwartz' laboratory, "Each cell is movement-sensitive and has a preferred direction; each neuron's preferred direction is like a vote. When the votes are added, we have the population vector."

The population vectors accurately predict the velocity of normal arm movement and, in this example, serve as a signal to convey the monkey's intention to the prosthetic arm. Because the software relies on only a small number of the thousands of neurons necessary for limb movement, the monkey did the rest of the work, learning through biofeedback how to modify the firing rates of the recorded neurons to refine the arm's movements.

Food was placed at different locations in front of the monkey and, with its own upper limbs restrained, the animal used the robotic arm to bring the food to its mouth.

"The next step is to add realistic hand and finger movement," says Meel Velliste, PhD, a postdoctoral fellow in the group. "This presents quite a challenge. We make hundreds of different subtle movements with our hands. We will need to interpret all of them."

The neuroprosthetic arm was developed by researchers at the University of Pittsburgh and custom built by Keshen Prosthetics of Shanghai, China. Software was developed at the University of Pittsburgh and Arizona State University. Modifications to the original arm were made at the Robotics Institute at Carnegie Mellon University.

In addition to Dr. Schwartz, Dr. Velliste, and Mr. Spalding, other investigators in the project include Beada Jarosiewicz, PhD, and Gordon Kirkwood, a bioengineering student at the University of Pittsburgh. ■

UPMC to launch Institute for Rehabilitation and Research at UPMC South Side

In September 2004, the University of Pittsburgh Medical Center announced the establishment of the UPMC Institute for Rehabilitation and Research (IRR) at UPMC South Side.

At the IRR, patients will have access to high-quality rehabilitation services, acute-care services, and pioneering research developments from the University of Pittsburgh's Department of Physical Medicine and Rehabilitation, ranked 8th in National Institutes of Health funding among departments of its kind.

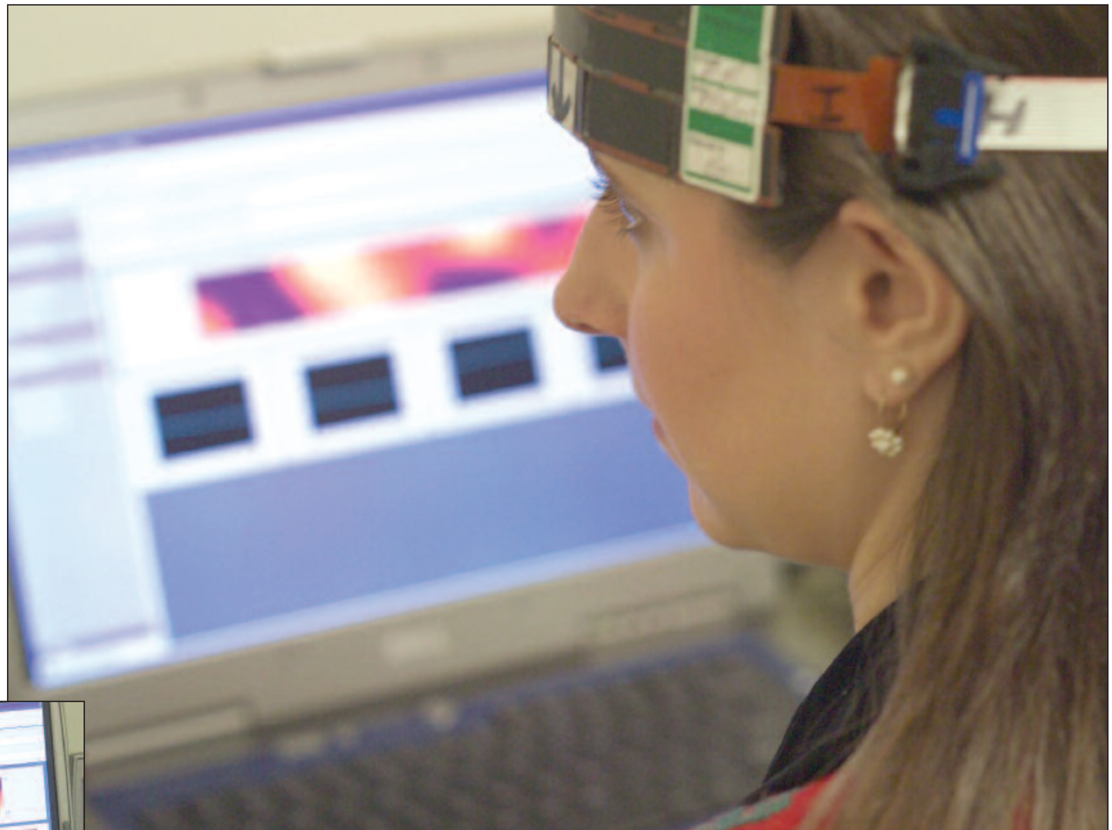
The IRR will serve as the hub of the UPMC Rehabilitation Network and will house facilities for both basic and clinical research programs. The new setting will provide an opportunity for extensive expansion of the University of Pittsburgh's basic and translational research endeavors. Efforts will focus on patients who need acute rehabilitation services, including those with neurodegenerative disease, peripheral nerve disorders, stroke, or injury of the brain or spinal cord.

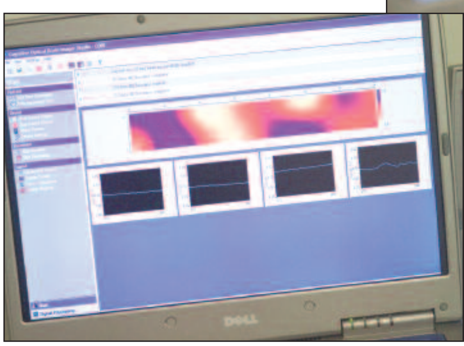
Proposed programs include a "Project to Cure and Treat Paralysis," which will focus on curative spinal cord therapies, technology to restore post-amputation functional deficits, the development of neuroprostheses (see Page 1), and growth factors for nerve regeneration after stroke or brain injury.

Patients who require more extensive inpatient rehabilitation therapy, and those participating in research studies, will be seen at UPMC South Side, a full-service hospital of UPMC, or one of the other seven inpatient, hospital-based facilities within UPMC. Patients requiring outpatient rehabilitation will be able to receive care — and benefit from IRR research — at any of the more than 40 outpatient facilities across western Pennsylvania that are part of the UPMC Rehab Network.

The UPMC Rehab Network is the largest network of rehabilitation facilities in the area. Through the network, patients with work- and sports-related injuries, stroke, orthopaedic disorders, and traumatic injuries of the brain and spinal cord can receive care from UPMC physicians, therapists, and specialists in a center close to home. ■

Researchers evaluate novel neuroimaging technology to assess brain injury





The fNIRS device measures cerebral blood flow (CBF) while the participant completes a computer-administered memory task. CBF values and oxygenation levels are displayed and stored on an additional laptop computer (see inset).

Advances in neuroimaging offer new ways to study the pathophysiology of brain dysfunction following traumatic brain injury (TBI). Traditional techniques, including computed tomography (CT) and magnetic resonance imaging (MRI) have demonstrated only limited correlation with TBI severity and post-TBI cognitive function.

However, researchers at the University of Pittsburgh Department of Physical Medicine and Rehabilitation have found that an innovative optical-imaging technique — functional near-infrared spectroscopy (fNIRS) — shows promise as a tool to study post-TBI neurocognitive compromise. fNIRS has already been applied in studies of cerebral blood flow.

fNIRS measures several physiological parameters related to cerebral blood flow, including changes in oxy- and deoxyhemoglobin. Thus, it is similar to other imaging technologies, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI).

However, fNIRS offers several practical advantages over these methods, according to Joseph Ricker, PhD, associate professor, physical medicine and rehabilitation. "Unlike PET and fMRI, fNIRS uses no ionizing radiation, does not require intravenous administration of isotopes or contrast agents, and does not require use of high-field magnetization or a large external scanner. It also offers the unique advantage of being highly portable and virtually unaffected by subject movement."

fNIRS has shown promise in gauging changes in cerebral functioning during cognitive tasks performed by healthy individuals. However, it has not been studied as a technique for investigating neurocognitive compromise after brain injury. The principal aims of this study are: 1) to validate the use of fNIRS in studying cognition after TBI; and 2) to use fNIRS to compare episodic-memory-related brain activity in injured versus non-injured people.

Researchers directly compare changes in CBF-related parameters within subjects and between groups using both fNIRS and fMRI during tasks that assess new learning. Currently, researchers are examining 15 subjects with a history of moderate to severe traumatic brain injury and 15 non-injured controls. The findings will serve as the basis for future investigations of cognition after TBI. Moreover, if fNIRS proves to be a valid post-TBI assessment tool, it will offer a form of neuroimaging that is accessible and applicable to evaluating pharmacologic and rehabilitative interventions. ■

Recently Published . . .

A small sample of representative papers by Department faculty members:

Kline AE, Yu J, Massucci JL, Zafonte RD, Dixon CE. Protective effects of the 5-HT_{1A} receptor agonist 8-hydroxy-2-(di-n-propyl-amino)tetralin against traumatic brain injury-induced cognitive deficits and neuropathology in adult male rats. *Neurosci Lett.* 2002; 333:179–82.

Wagner AK, Kline AE, Sokoloski J, Zafonte RD, Capulong E, Dixon CE. Intervention with environmental enrichment after experimental brain trauma enhances cognitive recovery in male but not female rats. *Neurosci Lett.* 2002; 334:165–8.

Wagner AK, Fabio A, Zafonte RD, Goldberg G, Marion DW, Peitzman A. Physical medicine and rehabilitation consultation: relationships with acute functional outcome, length of stay, and discharge planning after traumatic brain injury. *Am J Phys Med Rehabil.* 2003; 82:526–36.

Algood SD, Cooper RA, Fitzgerald SG, Cooper R, Boninger ML. Impact of a pushrim-activated power-assisted wheelchair on the metabolic demands, stroke frequency, and range of motion among subjects with tetraplegia. *Arch Phys Med Rehabil.* 2004; 85:1865–71.

Chaves ES, Boninger ML, Cooper R, Fitzgerald SG, Gray DB, Cooper RA. Assessing the influence of wheelchair technology on perception of participation in spinal cord injury. *Arch Phys Med Rehabil.* 2004; 85:1854–8.

Cooper RA, Wolf E, Fitzgerald SG, Kellerher A, Ammer W, Boninger ML, Cooper R. Evaluation of selected sidewalk pavement surfaces for vibration experienced by users of manual and powered wheelchairs. *J Spinal Cord Med.* 2004; 27:468–75.

Hunt PC, Boninger ML, Cooper RA, Zafonte RD, Fitzgerald SG, Schmeler MR. Demographic and socioeconomic factors associated with disparity in wheelchair customizability among people with traumatic spinal cord injury. *Arch Phys Med Rehabil.* 2004; 85:1859–64.

Kline AE, Massucci J, Dixon CE, Zafonte RD, Bolinger BD. The therapeutic efficacy conferred by the 5-HT_{1A} receptor agonist 8-hydroxy-2-(di-n-propylamino)tetralin (8-OH-DPAT) after experimental traumatic brain injury is not mediated by concomitant hypothermia. *J Neurotrauma* 2004; 21:175–85.

Lenze EJ, Munin MC, Quear T, Dew MA, Rogers JC, Begley AE, Reynolds CF. Significance of poor patient participation in physical and occupational therapy for functional outcome and length of stay. *Arch Phys Med Rehabil.* 2004; 85:1599–601.

Massucci JL, Kline AE, Ma X, Zafonte RD, Dixon CE. Time-dependent alterations in dopamine tissue levels and metabolism after experimental traumatic brain injury in rats. *Neurosci Lett.* 2004; 372:127–31.

Stuart M, Zafonte R. Fighting the silent epidemic: the Florida Brain and Spinal Cord Injury Program. *J Head Trauma Rehabil.* 2004; 19:329–40.

Wagner AK, Willard LA, Kline AE, Wenger MK, Bolinger BD, Zafonte RD, Dixon CE. Evaluation of estrous cycle stage and gender on behavioral outcome after experimental traumatic brain injury. *Brain Res*. 2004; 998:113–21.

Wolf EJ, Cooper RA, DiGiovine CP, Boninger ML, Guo S. Using the absorbed power method to evaluate effectiveness of vibration absorption of selected seat cushions during manual wheelchair propulsion. *Med Eng Phys.* 2004; 26:799–806.

Zafonte R, Lombard L, Elovic E. Antispasticity medications: uses and limitations of enteral therapy. *Am J Phys Med Rehabil.* 2004; 83:S50–8.

Cohen LJ, Fitzgerald SG, Lane S, Boninger ML. Development of the seating and mobility script concordance test (SMSCT) for spinal cord injury: obtaining content validity evidence. *Assist Technol,* in press, 2004.

Cooper RA, Cooper R. Design of an arm-powered general purpose tricycle for use by people with mobility impairments. *J Disabil Rehabil,* in press, 2004.

Souza AL, Boninger ML, Fitzgerald SG, Shimada SD, Cooper RA, Ambrosio F. Upper limb strength in wheelchair users with paraplegia. *J Spinal Cord Med,* in press, 2004.

Wainner RS, Fritz JM, Irrgang JJ, Delitto A, Allison S, Boninger ML. Development of a clinical prediction rule for the diagnosis of carpal tunnel syndrome. *Arch Phys Med Rehabil,* in press, 2004.

Dvorznak MJ, Cooper RA, Boninger ML. Kinematic analysis for determination of bioequivalence of a modified hybrid III test dummy and a wheelchair user. *J Rehabil Res Dev.* Accepted for publication, 2004.

For more information on any of these publications, call 412-648-6979.

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.

Studies evaluate new generation of mobility aids

Mobility technology reaches a new high

Research conducted at the University of Pittsburgh contributed to FDA approval of the Independence 3000 IBOT Transporter, an innovative adaptation of the standard wheelchair that allows improved negotiation of obstacles like stairs and uneven pavement. It can also balance on two rear wheels, permitting the user to reach items normally out of reach to wheelchair users, and to move about and converse with others at standing eye-level.

The IBOT uses an advanced gyro-balanced system for stable operation in four functions: standard, balance (raised on two rear wheels), four-wheel (for inclines, curbs, and uneven terrain), and remote (for loading the unoccupied chair into vehicles). An integrated system instantly and automatically responds to the seat's movement and the user's center of gravity. A backup system assures user safety.

The transporter was evaluated for safety and ease of use in phase 1 trials conducted by co-principal investigators Michael L. Boninger, MD, professor of physical medicine and rehabilitation, University of Pittsburgh School of Medicine; and Rory A. Cooper, PhD, professor and chairman of the Department of Rehabilitation Science and Technology, University of Pittsburgh School of Health and Rehabilitation Science.

FDA approval was fast-tracked because the technology was seen as a breakthrough of potentially great benefit to people with disabilities. Subsequent phases tested the IBOT in home, community, and work environments with favorable results. The home-community phase concluded that the IBOT expands options for wheelchair users and is most useful outdoors where previously inaccessible areas are now traversable. Participants in the work environment testing were veterans with spinal cord injury; all were wheelchair users, and all worked in an office environment.

Using the IBOT, participants were able to traverse rough terrain, climb curbs and stairs, and hold conversations at standing eye-level. Half of the users felt that the IBOT would help them at work, and all thought that it should be made available to veterans who use wheelchairs.

The 3000 IBOT received FDA approval in August 2003. Researchers recommend further study to determine if the IBOT affects workers' ability to return to work and if it improves performance on the job. ■

Above photograph: The 'Balance' feature of the Independence 3000 IBOT Transporter extends the user's vertical reach and allows eye-level contact with standing companions.

Photograph reprinted from: Cooper RA, Boninger ML, Cooper R, Dobson AR, Kessler J, Schmeler M, Fitzgerald SG. Use of the Independence 3000 IBOT Transporter at home and in the community. *J Spinal Cord Med.* 2003; 26:79-85. © 2003 American Paraplegia Society. Reprinted with permission.

Power boost eases upper-body strain

It is estimated that between 30 and 70 percent of long-term manual wheelchair users eventually develop a degenerative condition of one of the upper-extremity joints. Overuse injuries in manual wheelchair users result from repetitious motion and the force needed to propel the chair. The strain often leads to mobility-limiting pain, progressing to further disability or injury that eventually requires surgical correction, with further limitations on mobility and independence.

University of Pittsburgh researchers are conducting phase 3 trials of a mobility aid that offers wheelchair users a noteworthy middle-road option. Michael L. Boninger, MD, and Rory A. Cooper, PhD, are assessing the JWII Pushrim-Activated Power-Assist Wheelchair (PAPAW) as a way to reduce strain on the upper body and limbs of manual wheelchair users with tetraplegia.

The PAPAW (Yamaha Motor Corporation, Japan) uses novel technology to provide a battery-powered boost that amplifies the manual force applied to the pushrim of the wheel when the user is propelling or braking the wheelchair.

Phases 1 and 2 of the investigation are complete. Fifteen subjects were tested in phase 1, in which the amount of energy needed for manual-wheelchair operation was compared to the energy needed to operate a power-assisted wheelchair. The study showed a significant decrease in energy expenditure as well as reduction in the stroke frequency required to maintain a preset target speed while using the PAPAW. Reducing stroke frequency decreases the risk of developing upper-extremity pain or repetitive-stress injury. Use of the PAPAW also resulted in a significant decrease in heart rate, ventilation, and oxygen consumption when compared to manual wheelchair propulsion.

In phase 2, fifteen subjects were evaluated at the University of Pittsburgh's Center for Assistive Technology (CAT) using the PAPAW on a course constructed to replicate situations and obstacles encountered in performing activities of daily living (ADL). Participants preferred the PAPAW when completing the ADL course. Overall heart rate again showed a significant decrease compared to heart rate during manual wheelchair use.

Recruitment is now under way for phase 3 of the study. Unlike phases 1 and 2, which demonstrated the PAPAW's efficacy in laboratory settings, phase 3 testing compares the device to an unassisted manual wheelchair in community settings. Researchers are recruiting four participants with tetraplegia (SCI at the cervical level or above), who use a manual wheelchair on a full-time basis. Study participants will use a PAPAW for two weeks in their own homes, where performance in predetermined activities will be monitored. ■

From the Chairman's Desk

This second issue of *Rehab Progress* highlights more exciting developments in rehabilitation at the University of Pittsburgh and the University of Pittsburgh Medical Center (UPMC).

Foremost is the establishment of the UPMC Institute for Rehabilitation and Research (IRR) at UPMC South Side (see Page 2). Housing and supporting the clinical programs of the UPMC Department of Physical Medicine and Rehabilitation, as well as basic, translational, and clinical research programs, the IRR will play a key role in addressing the growing public health problem of physical disability. The Department's NIDRR Model Center for Spinal Cord Injury Care and the NIDRR Traumatic Brain Injury Model System Center operate within the framework of the IRR, as will our NIH Clinical Trials center. Perhaps most important is the development of our new Project to Cure and Treat Paralysis. This project has been established with a "Marshall Plan" sense of urgency to recruit basic and clinical science faculty and develop innovative programs that will have an impact on the lives of people with disability.

In this issue, you find more updates on the ways that the IRR is adding to "Rehab Progress": On Page 1, we describe some of the fascinating work of IRR researcher Andrew Schwartz, PhD, with neural prostheses; Joseph Ricker, PhD, is studying the use of a more "portable" method of neuroimaging; Michael Boninger, MD, and Rory Cooper, PhD, report on two innovative mobility aids.

Lastly, you will see listed a small sample of our faculty members' recent publications. From time to time, *Rehab Progress* will highlight the activities and accomplishments of our faculty, including presentations and awards. Future issues will focus on innovative basic and clinical science programs in musculoskeletal medicine and new clinical trials.

Sincerely,

Ross D. Zafonte

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

UPMC | University of Pittsburgh Medical Center

200 Lothrop Street
Pittsburgh, PA 15213-2582

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.