Technology and Disability 22 (2010) 161–165
DOI 10.3233/TAD-2010-0307
IOS Press

Guest Editorial

State of the Science for Pediatric Rehabilitation Engineering

Richard Foulds* and Sergei Adamovich
Department of Biomedical Engineering, New Jersey Institute of Technology, Newark, NJ, USA

1. Introduction

Over the past 25 years the field of rehabilitation engineering has recognized the need for a specific focus on the technological needs of children with disabilities as those needs often differ from those of adults [2]. Among the important efforts in a number of nations has been the support of a Rehabilitation Engineering Research Center (RERC) on technology for children with orthopedic disabilities by the United States Department of Education. The National Institute on Disability and Rehabilitation Research (NIDRR) earliest RERC on pediatrics influenced national rehabilitation policy and had a significant impact on the 'Tech Act' legislation of the early 1990s [13]. The NIDRR shifted the focus of this RERC in 1990 from leading the creation of technology service infrastructure to conducting research and development in the area of prosthetics and orthotics for children with orthopedic disabilities. The legacy of the Rancho Los Amigos RERC over its three funding cycles from 1990 to 2005, is now seen in a large number of commercially available products that meet the needs of children.

Later, the NIDRR again shifted the focus of its pediatric RERC to newly emerging issues, and awarded this RERC on Technology for Children with Disabilities to our partnership between New Jersey Institute of Technology and the Childrens' Specialized Hospital. We introduced the blending of emerging biomechanics, neuroscience and cognitive science with new therapeutic technologies for manipulation, mobility, and bone health, along with new approaches that encouraged cortical reorganization through virtual reality and robotic interventions. In addition, the NIDRR charged our Center with a responsibility to explore emerging new discoveries in the broad areas of medicine, engineering, biology and neuroscience, and identify emerging trends and knowledge that will serve as the foundation for a new generation of pediatric rehabilitation engineering research. The six papers included in this special issue have been selected from an exciting collection of presentations given at a State of the Science Workshop organized by our RERC.

Unlike some State of the Science Workshops, we chose not to highlight current engineering work conducted in our laboratories, but instead invited 13 speakers who were highly regarded in their own areas of specialization, and who came from quite diverse backgrounds. We sought to generate a synergy among this group and the audience of 60 faculty, physicians, students, clinicians, manufacturers and people with disabilities. Our goal was not to duplicate the role provided by national conferences and professional journals. Only a few speakers had previously met or were familiar with the research of other presenters. Most regularly attend different professional meeting, belong to different communities of scholars, and publish in different journals.

2. The distinctive perspective of pediatrics

One thread that was evident throughout the workshop was the notion that pediatrics means more than

*Corresponding author. E-mail: Foulds@ADM.NJIT.EDU.

ISSN 1055-4181/10/$27.50

simply small in size. There is a distinct perspective on work with children that identifies the need for research that may differ from adult research. Andrew Gordon's presentation on Constraint Induced Therapy children with cerebral palsy set this tone in the Workshop's first presentation [9]. Gordon noted that while CIT was initially developed for individuals with hemiplegia due to a stroke, and children with cerebral palsy may also have hemiplegia, one must be careful to simply assume that this adult treatment can be applied to these children. He identified the important distinction that adults would have learned complete motor control prior to their impairment, and that CIT may assist them in relearning or reacquiring functions that had been previously well-practiced. In contrast, children, born with cerebral palsy, will not have the advantage of regular motor development. Applying CIT or any other mode of therapy to these children cannot depend upon restoring lost function (function that was acquired by adults during their important developmental period in childhood) but must concentrate on assisting the child to develop function. He stressed the need to work with children with disabilities during their normal developmental periods to take advantage of natural opportunities for neuroplasticity.

Susan Fasoli spoke about the work at MIT in which successful robotic stroke therapy techniques had been applied to children with cerebral palsy [4]. Much of the work to date has been focused on adapting the robots and their therapies to the physical scale and interest levels of children. While the results are encouraging, with measureable improvements in upper-limb movement, increases in specific joint range of motion, in smoothness of some multijoint arm trajectories, these projects have only begun to identify the therapeutic interventions that may lead to improved function in a child's daily activities. Fasoli presented what could be the beginning of such functional improvements with her data showing that in a follow-up questionnaire, parents of the children in her study report gains in the daily use of paretic limb. How much improvement, and to what extent that improvement is functionally beneficial remains to be evaluated.

Paolo Bonato reported on his work on Lokomat training of children with cerebral palsy [14]. While the Lokomat was initially developed for body-weight supported gait training of persons with incomplete spinal cord injury, he is examining the potential benefits of this robotic system for improving gait in children who have intact spinal cord function, but whose coordination and motor control is impaired by neural lesions. His subjects were diagnosed with spastic cerebral palsy, and were capable of ambulation with difficulty (including using assistive technology). His results are also encouraging, with significant improvements shown in post-intervention measures of walking function (GMFM Walking Function), standing (GMFM Standing function), and kinematic measures of walking speed and stride length.

During the discussion periods, a number of participants emphasized that research on such therapeutic methods must address the specific issues related to pediatrics. Motor control develops as a child matures. Such interventions must account for the lack of prior learning and must take advantage of time-critical opportunities for neuromotor development that occur during the early years of life.

3. New scientific basis for future pediatric rehabilitation engineering

We were pleased that our presenters brought examples of new scientific studies that may change the ways in which NIDRR can define the future of rehabilitation engineering research. John Martin ([12] spoke about his investigation into the possible causes of functional disabilities. He explained the analogy of the condition of 'lazy eye', which begins as a neuromuscular problem and then evolves into functional blindness. This is not true blindness with an absence of visual information, but a condition in which some sensory information is learned to be excluded. He proposed that hemiplegia may have similarities, beginning with motor control difficulty and progressing to a functional paralysis. His work involves the study of synaptogenesis during the post-natal period. He believes that there is neural competition that refines synaptic connections. This competition is activity dependent, and influences the post-natal neural remodeling that eventually defines the ipsilateral and contralateral balance necessary for normal motor control, with an increase in contralateral processes. He has an animal model in which arbitrary attenuation of competitive signals changes the bilateralization of the spinal cord, with a much higher degree of ipsilateral control maintained. Martin relates this to neuromotor disability with the idea that limitation of activity on one side of the body that results from an initial disability with increased preference for the less impaired side shifts the competition to the advantage of the less impaired side. This reduced competition from the impaired side results in neural remodeling that further limits the use of that side.

He suggests that the clinical progression of spasticity, which is not present initially in newborn children with cerebral palsy or immediately following a stroke in an adult, but increases over time, as an example how one form of limitation may result in a form of unintended neural learning that introduces further loss of function. Martin's work provides a potentially important understanding of the progression of impairment, and offers an explanation for the apparent success of CIT and some robot-assisted therapies. His notion of competitive learning is based on creating a balance of activity between the competing articulators that induces the correct balance of contralateral processes. He suggests that CIT reintroduces competition by decreasing the over-activity of the less impaired side, while increasing the activity of the silent or impaired side. An extension of his thinking is that therapeutic interventions that encourage use of the impaired side will induce the neural remodeling process to gradually increase the strength of contralateral connections and reduce the strength of abnormal ipsilateral connections.

Eileen Fowler [7] from UCLA described her studies on selected voluntary motor control, in which she has observed that children with cerebral palsy often exhibit impaired ability to isolate joint movement. There is often an imprecision in joint control that is typified by abnormal coupling with adjacent joints, or mirrored in the same joint on the contralateral side. Her work includes consideration of the specificity of descending signals within corticospinal tracts, and the abnormal overlap of signals among tracts.

Gerald Harris' paper bridged the traditional areas of pediatric movement analysis with these newer concepts of motor control and intervention [11]. He reminds us that assessment of improved function must accompany all investigations of new therapeutic interventions. Clearly, if attempts to apply mass practice methods to encourage neuroplastic changes are to be deemed successful, there must be accompanying quantitative measures of meaningful improvement in walking and reaching.

4. Summary

Harris' theme of assessment was further emphasized by Mathijs Soede (Editor of Technology and Disability) in his closing talk of the Workshop, and resonated throughout the discussions on knowledge transfer to commercialization and clinical service addressed the relevance of these new interventions. Of concern was whether or not statistical significance correlated with useful function. When we are told that CIT is beneficial or that robot or VR therapy produces changes in one or more scales, it is important to understand how that translates into daily use. Does improving a child's stride length by 10% improve his/her walking? Is a change in the walking function of a clinical assessment tool sufficient to allow independent ambulation? Do significant changes in upper extremity test scores mean that a child will now be able to perform tasks with greater accuracy or without assistance? Does an improvement in gross arm control mean much if precise finger control does not improve as well? Are we attempting to provide fully normal control to the more affected limb, or are we trying to provide a degree of usefulness in support of the less affected limb? When we improve function of a specific joint or limb, can that be used as part of a two handed or two legged coordinated task?

An important thread, which essentially became a major theme of our workshop and is reflected in the papers of this special issue is that future pediatric rehabilitation engineering research should address the technological exploitation of the emerging science of motor control. While pediatric rehabilitation engineering of the past was targeted at developing new assistive technologies that accommodated disabilities, or conducted gait studies to provide improved assessment, we are now at a point where it is possible to imagine engineering research that can support new technologies and therapeutic interventions that can be expected to change physical performance and lead to significant improvements in function.

Studies now give us confidence that it may be possible to provide interventions that can access the power of neuroplasticity. This could involve the learning of new skills, or the rewiring of functioning cortical areas to bypass damaged pathways. Other studies could involve the encouragement of movements that will promote a proper balance in contralateral control or in countering gravity to reduce the effect of abnormal synergies.

Important aspects of an engineering approach were presented to our Workshop by Fasoli and Bonato as they showed that robotic devices (for both upper and lower extremities) have the ability to provide consistent intervention that can initiate measureable improvement in clinically acceptable function. They highlighted not only that these methods can work with children, but also have the potential to engage the interest of children for sufficient time to make the interventions effective. The child is encouraged to make therapeutically beneficial movements of the arms and body in order to play the games. Similar promising studies on the effects of robot-assisted training in children has been produced by other groups [1,8] and by our Center [5,15]. Their work, as with all the other neuromuscular interventions presented at our Workshop, is based on the encouragement of active and purposeful movements, made in sufficient quantity to induce neural changes. Movement and volition, as well as a large number of repetitions appear to be essential.

To accomplish sufficient levels of user compliance, we see that the use of technologies, either robotic or virtual can improve the efficiency of expensive human therapy. Such technology of the future will likely be more beneficial if it can accommodate the needs of the individual user as closely as possible. The video games that reinforce specific clinical goals for an individual and change as the individual's skills improve will likely have stronger results than more general games. Robots that support specific user defined movements and respond to user intention will also be potentially more useful than exercise machines that execute non-user-specific exercises. Such systems can offer the therapeutic benefits of CIT and other interventions without the necessity to bind the less affected limb and can possibly allow the therapy to be more subtle and fit more effectively into the daily routine.

Several important discussions reported in the literature echo similar themes. The Section on Pediatrics of the American Physical Therapy association summit on pediatrics research [6] addressed the impact of a lack of exercise of the upper and lower extremities as a contributor to the development of secondary disabilities in children with orthopedic impairments. They argue that new methods are required to increase muscle strength, improve coordination, reduce the potential of inefficient behaviors and overuse, to reduce musculoskeletal damage, and to facilitate proper cardiovascular function.

The theme of neurally-based therapies applied to children was highlighted in a 2008 workshop sponsored by the NIDRR RERC on Machines Assisting Recovery from Stroke (MARS) and the Cerebral Palsy International Research Foundation. The report of this meeting [10] begins with the statement that current and emerging technologies that are showing benefits to neural recovery in persons with stroke "have not routinely found their way to analogous disorders in childhood" and noted that while 2428 publications are listed by the National Library of Medicine under technology applied to stroke, only 287 are listed for technology applied to cerebral palsy. The workshop posed the questions of how the problems studied in cerebral palsy and stroke converge or overlap, and in what ways are they different. W. Zev Rymer, director of the MARS RERC noted that impairments of adults recovering from a stroke 'broadly resemble' those of children with cerebral palsy and that work should be undertaken to explore the application of successful stroke methods and technologies to children. Further support for the translation of neurally-based rehabilitation methods is provided by Dobkin [3], who presents evidence of common denominators between stroke and traumatic brain injury that allow similar therapeutic technologies to be applied. Among the concepts that the workshop participants believed could become transformational approaches for children with cerebral palsy are robot assisted therapy, computational models of stroke and neuromotor behavior, brain imaging, virtual reality therapy, volitional patient participation as opposed to passive therapy, combining different modes of therapy, and effective clinical measures of functional gains. In conclusion, several promising lines of inquiry have been discussed, and there is a clear indication for an increased effort to expand the pediatric-specific neurorehabilitation approaches and continued efforts to translate knowledge developed in adult rehabilitation research and better understanding of the principles of neuroplasticity developed in animal experiments into pediatric rehabilitation practice.

References

[1] I. Borggraefe, L. Kiwull, J.S. Schaefer, I. Koerte, A. Blaschek, A. Meyer-Heim and F. Heinen, (2010) Sustainability of motor performance after robotic-assisted treadmill therapy in children: an open, non-randomized baseline-treatment study, *European Journal of Physical Rehabilitation Medicine* **46** (2010), 125–131.

[2] K.W. Burkett, Trends in pediatric rehabilitation, *Nursing Clinics of North America* **24**(1) (1989), 239–255.

[3] B.H. Dobkin, Motor rehabilitation after stroke, traumatic brain, and spinal cord injury: Common denominators within recent clinical trials, *Current Opinion in Neurology* **22** (2009), 563–569.

[4] S. Fasoli, M. Fragala-Pinkham, R. Hughes, N. Hogan, J. Stein, H.I. Krebs, Upper limb robot-assisted therapy: A new option for children with hemiplegia, *Technology and Disability* **22** (2010), 193–198.

[5] G.G. Fluet, Q. Qiu, D. Kelly, H.D. Parikh, D. Ramirez, S. Saleh and S.V. Adamovich, Interfacing a haptic robotic system with complex virtual environments to treat impaired upper extremity motor function in children with cerebral palsy, *Developmental Neurorehabilitation* **13**(5) (2010), 335–345.

[6] E.G. Fowler, T.H.A. Kolobe, D.L. Damiano, D.E. Thorpe, D.W. Morgan, J.E. Brunstrom, W.J. Coster, R.C. Henderson, K.H. Pitetti, J.H. Rimmer, J. Rose and R.D. Stevenson, Promotion of physical fitness and prevention of secondary conditions for children with cerebral palsy: Section on Pediatrics Research Summit Proceedings, *Physical Therapy* **87**(11) (2007), 1495–1510.

[7] E.G. Fowler, Concepts in spasticity and selective motor control in children with spastic cerebral palsy, *Technology and Disability* **22** (2010), 207–214.

[8] F. Frascarelli, L. Masia, G. Di Rosa, P. Cappa, M. Petrarca, E. Castelli and H.I. Krebs, The impact of robotic rehabilitation in children with acquired or congenital movement disorders, *European Journal of Physical and Rehabilitation Medicine* **45** (2009), 135–141.

[9] A.M. Gordon, Augmenting pediatric constraint-induced movement therapy and bimanual training with video gaming, *Technology and Disability* **22** (2010), 179–191.

[10] D. Kerkovich, Transformational technologies in single-event neurological conditions: Applying lessons learned in stroke to cerebral palsy, *Neurorehabilitation and Neural Repair* **23**(7) (2009), 747–765.

[11] J.T. Long and G.F. Harris, Pediatric gait and motion analysis: Advances in biomechanics and clinical assessment, *Technology and Disability* **22** (2010), 199–205.

[12] J.H. Martin, K. Friel, S. Chakrabarty and I. Salimi, Harnessing activity-dependent plasticity in the developing corticospinal system to restore motor function after perinatal brain injury, *Technology and Disability* **22** (2010), 167–177.

[13] M. Milner, S. Naumann, W. Literowich, M. Martin, S. Ryan, W.F. Sauter, G.F. Shein and G. Verburg, Rehabilitation engineering in pediatrics *Pediatrician* **17**(4) (1990), 287–296.

[14] B.L. Patritti, M. Sicari, L. Deming, F. Romaguera, M. Pelliccio, P. Kasi, M.G. Benedetti, D. Nimec and Bonato, The role of augmented feedback in pediatric robotic-assisted gait training: A case series, *Technology and Disability* **22** (2010), 215–227.

[15] Q. Qiu, D.A. Ramirez, S. Saleh, G.G. Fluet, H.D. Parikh, D. Kelly and S.V. Adamovich, (2009) The New Jersey Institute of Technology Robot-Assisted Virtual Rehabilitation (NJIT-RAVR) system for children with cerebral palsy: a feasibility study, *Journal of Neuroengineering and Rehabilitation* **16**(6) (2000), 40.