Innovative Power Wheelchair Control Interface: A Proof-of-Concept Study

Sandra L. Winkler, Sergio Romero, Emily Prather, Marisa Ramroop,
Emmy Slaibe, Matthew Christensen

MeSH TERMS

- durable medical equipment
- lower extremity
- man-machine systems
- orthotic devices
- wheelchairs

Some people without independent mobility are candidates for powered mobility but are unable to use a traditional power wheelchair joystick. This proof-of-concept study tested and further developed an innovative method of driving power wheelchairs for people whose impairments prevent them from operating commercial wheelchair controls. Our concept, Self-referenced Personal Orthotic Omni-purpose Control Interface (SPOOCI), is distinguished by referencing the control sensor not to the wheelchair frame but instead to the adjacent proximal lower-extremity segment via a custom-formed orthosis. Using a descriptive case-series design, we compared the pre–post functional power wheelchair driving skill data of 4 participants, measured by the Power Mobility Program, using descriptive analyses. The intervention consisted of standard-care power wheelchair training during 12 outpatient occupational or physical therapy sessions. All 4 participants who completed the 12-wk intervention improved their functional power wheelchair driving skills using SPOOCI, but only 3 were deemed safe to continue with power wheelchair driving.

Winkler, S. L., Romero, S., Prather, E., Ramroop, M., Slaibe, E., & Christensen, M. (2016). Brief Report—Innovative power wheelchair control interface: A proof-of-concept study. *American Journal of Occupational Therapy*, 70, 7002350010. <http://dx.doi.org/10.5014/ajot.2016.015750>

Sandra L. Winkler, PhD, OTR/L, is Research Health Science Specialist, James A. Haley Veterans' Hospital, Center of Innovation in Disabilities and Rehabilitation Research, Tampa, FL; sandra.winkler@va.gov

Sergio Romero, PhD, is Research Assistant Professor, Department of Occupational Therapy, University of Florida, Gainesville.

Emily Prather, OTR, is Occupational Therapist, University of Colorado Health at Memorial Hospital, Colorado Springs.

Marisa Ramroop, OTR, is Graduate, Department of Occupational Therapy, Nova Southeastern University, Fort Lauderdale, FL.

Emmy Slaibe, OTR, is Occupational Therapist, St. Catherine's West Rehabilitation Hospital, Miami, FL.

Matthew Christensen, MS, is CAD Engineer, ConforMIS, Inc., Boston, MA.

Some people without independent mobility are candidates for powered mobility but are unable to use a traditional power wheelchair (PW) joystick (Fehr, Langbein, & Skaar, 2000; Stewart, Noble, & Seeger, 1992). People with severe motor impairment of the upper quadrants are limited in their use of technology (e.g., PWs, computers, and alternative and augmentative communication devices). Most existing interfaces to PWs require either upper-extremity control to use traditional proportional joysticks or discrete interfaces or head control to use a head pointer or chin joystick. As a result, use of standard-interface strategies and products is ruled out for this population. The purpose of this proof-of-concept study was to test and further develop an innovative method of driving PWs for people who are candidates for powered mobility but whose impairments prevent them from operating commercial wheelchair controls.

Our concept is distinguished by referencing the control sensor not to the wheelchair frame but instead to the adjacent proximal lower-extremity segment via a custom-formed orthosis. We refer to our concept as a *Self-referenced Personal Orthotic Omni-purpose Control Interface*, abbreviated *SPOOCI* and pronounced “spooky” as an intentional reference to the near-magical sight of a person driving a PW (or moving a computer cursor, operating job-site machinery, or communicating with an augmentative and alternative communication product) without any visible externally referenced control interface. For example, a SPOOCI could be shaped and finished to look more shoelike, covered with a red fabric to resemble glitter shoes available to nondisabled young female peers or tooled and embroidered like Western boots. Even without these cosmetic enhancements, some children may find it appealing to control a PW in a magical way—by invisible means—thus improving appeal and minimizing stigmatizing features.

Our rationale for developing and evaluating SPOOCI derives from these three lines of reasoning:

1. Moving the sensor reference frame from the wheelchair to the user's body may reduce involuntary neuromuscular activity triggered by reaching and postural maintenance in people with abnormal muscle tone (i.e., athetosis, dystonia, ataxia). As a result, the signal-to-noise ratio during system control is improved; that is, control is less distorted by unintended motor output.
2. By providing a wearable interface, SPOOCI eliminates the effort and attention associated with positioning a limb to grasp an externally mounted control.
3. The spurious inputs to a PW control interface that can result from inertial effects on the user's limb during changes in speed and direction will be reduced if the interface is not referenced to the wheelchair frame.

Although we have designed, built, and tested a proof-of-concept prototype of an innovative PW control technology based on the SPOOCI concept, patented with the U.S. Patent Office (Patent No. 8,244,655 B2), it has been demonstrated only briefly by able-bodied engineering students. The prototype that was tested resembled a sandal. The second prototype, tested in this study, was designed to interface with any body part, rather than just with the foot. The interface itself was a pneumatic bulb. The purpose of the project described in this article was to further develop our design and pilot test it with the intended population—people with severe motor impairment of the upper quadrants—and to evaluate improvement in functional wheelchair driving achieved using SPOOCI.

Method

This study was approved by the University of Florida and the University of Vermont institutional review boards (IRBs).

Design

A descriptive case-series design was used to collect data pre- and postintervention for this proof-of-concept study (Kooistra, Dijkman, Einhorn, & Bhandari, 2009).

After signing the informed consent, participants were evaluated for a custom PW by a team that included the participant and family or caregiver, researchers, a vendor (a Rehabilitation Engineering and Assistive Technology Society of North America–certified assistive technology practitioner), and the occupational therapist or physical therapist treating the participant, and the order for the custom wheelchair was placed. Custom PWs were ordered for 4 of the 5 participants and delivered to the study site; 1 of the participants chose to use his own PW (which the participant could not drive independently or safely). At the end of the study, the PWs were donated to a local organization that then donated them to the participants.

To obtain IRB approval for a Food and Drug Administration–exempt experimental device, a standard-care intervention was implemented, meaning that participants learned how to drive a PW just as they would have had they not been enrolled in this study. During the standard-care intervention, participants practiced PW driving during regularly scheduled 45-min weekly occupational therapy or physical therapy sessions using SPOOCI. Practice was performed under direct supervision of an occupational therapist or physical therapist. The PW was equipped with a kill switch, and the speed of the PW was set to slow and increased as participants' skill improved. Practice consisted of driving the PW with SPOOCI around a track that had been set up in the clinic using colorful duct tape. Once participants were safe on this large oval track, they began driving down the halls and outside in the parking lot where cones were set up. Hands-on and verbal assistance were provided as needed. Participants were required to attend at least 10 of the 12 sessions, allowing for illness and scheduling conflicts. Data for the first 10 sessions completed were analyzed.

Participants

Five participants (2 children, 3 adults) were recruited from the UF Health Shands Rehabilitation Center at Magnolia Park, where the study took place. Inclusion criteria were as follows: (1) severe upper-

extremity motor impairment (Level 5 on the Gross Motor Function Classification System; Palisano, Rosenbaum, Walter, Wood, & Galuppi, 1997); (2) inability to drive a PW safely and unsupervised; (3) at least age 23 mo (with a preference for older children and adults who could provide verbal insight into their experience); and (4) receiving or eligible to receive occupational therapy or physical therapy services a minimum of once per week for 12 wk (the duration of the intervention). Exclusion criteria were as follows: (1) nonmastery of cause and effect (based on therapist–principal investigator observation) and (2) worse than mildly impaired vision. Participants were recruited via IRB-approved flyers disseminated to colleagues in the Gainesville, Florida, area.

Outcome Measure

The Power Mobility Program (PMP; Furumasu, Guerette, & Tefft, 1996) was administered before and after the 12-wk intervention to determine change in functional driving ability. The PMP is a hierarchical 34-item set of tasks designed to evaluate PW mobility skills in young children. Of the items, 17 evaluate basic PW driving skills, such as starting, stopping, and directional control. The remaining 17 PMP items evaluate functional skills, including maneuvering the PW through a doorway, driving down a ramp, and avoiding surface irregularities such as potholes or gratings. Only the first 14 of the basic 17 PMP items were relevant to the intervention and were thus used in this study (6 Beginning Mobility skills items, 7 Direction Control skills items, and 1 Speed Control skills item).

Each item is scored on a scale ranging from 0 to 5 according to the level of verbal and hands-on assistance needed to drive safely, with 0 indicating that the task was not attempted; 1, maximal hands-on assistance was needed; 2, minimal hands-on assistance was needed; 3, direct standby assistance was needed; 4, only verbal cueing was needed; and 5, only age-appropriate supervision was needed. The maximum score is 85. The PMP is a performance-based instrument; no known studies have assessed its reliability and validity.

Data Collection and Analyses

Preintervention PMP outcome data were collected at the beginning of Session 1, and postintervention PMP data were collected at the end of Session 10. Because of the small sample size, descriptive statistics were used to compare pre- and postintervention scores and were reported case by case.

Results

Five participants began the study. One participant was unable to complete the intervention as a result of prolonged hospitalization. The remaining 4 participants completed the required 10 sessions during the 12-wk intervention period.

Participant 1

Participant (P) 1 was an adult man with hemiplegia resulting from a traumatic brain injury incurred as a child. P1 had previous experience with a PW, but for safety reasons its use was discontinued; P1 had not owned or used a PW for many years. While being fitted for the custom PW that would be ordered for him for the study, P1 was able to drive the high-end demonstration PW using the standard joystick within 2–3 min. P1 used SPOOCI with his nonhemiplegic hand and knees; a pneumatic bulb in his hand controlled left and right, and a pneumatic bulb between his knees controlled forward and stop (Figure 1). P1's PMP score increased from 16 to 85 using SPOOCI. P1 preferred and continued to drive his PW with the traditional joystick using his nonhemiplegic arm.

Participant 2

P2 was an undiagnosed adult woman with spasticity and decreased motor control in all four extremities but more pronounced on the right side. She lived in a group home. P2 had no previous experience with a PW. She used a manual wheelchair that she propelled with her foot and the assistance of a caregiver. P2's best PW driving occurred while she was using one pneumatic bulb between her left forearm and the PW armrest and another between her left foot and the PW footrest (Figure 2). P2's PMP score

Figure 1. Adult man with hemiplegia using SPOOCI with his nonaffected arm to turn right and left and his knees to go forward and stop.

Note. SPOOCI = Self-referenced Personal Orthotic Omni-purpose Control Interface.

increased from 13 to 25 using SPOOCI. Overall, P2 continued to require minimal hands-on assistance for safety. She had several seizures during the trials and also demonstrated defiant behaviors; she either could not or would not follow instructions. The research and clinical team could not determine whether this behavior was behavioral or cognitive or related to medication. Because of these complications, P2 was the only participant that the team

(including the caregiver) determined was not a candidate for powered mobility.

Participant 3

P3 was a girl with a history of shunt failure who had previous PW experience and owned a PW but was unable to drive it independently and safely. P3 was hospitalized for an extended period shortly after the study began and did not complete the study. Before her hospitalization, P3 used SPOOCI with

Figure 2. Undiagnosed adult woman with spasticity and decreased motor control in all four extremities using SPOOCI between her left forearm and the armrest to go forward and stop.

Note. SPOOCI = Self-referenced Personal Orthotic Omni-purpose Control Interface.

Figure 3. Girl using SPOOCI in one hand for forward and stop and the other hand to turn left and right.

Note. SPOOCI = Self-referenced Personal Orthotic Omni-purpose Control Interface.

Figure 4. Boy with spastic, quadriplegic cerebral palsy using SPOOCI between his right forearm and left elbow; this proved not to be the ideal placement.

Note. SPOOCI = Self-referenced Personal Orthotic Omni-purpose Control Interface.

her hands; a pneumatic bulb in one hand controlled forward and stop, and a pneumatic bulb in the other hand controlled left and right (Figure 3).

Participant 4

P4 was a boy with spastic, quadriplegic cerebral palsy who owned his own PW but was unable to drive independently and safely. P4 was tilted back in his PW to keep him from falling forward, which affected his ability to see where he was going. The higher end test chair provided P4 with more trunk support, thus allowing him better use of his vision. Optimal placement of the pneumatic bulbs for P4 was between his forearms and on his lap-board (Figure 4); however, the pneumatic bulbs required a larger range of flexion and extension than P4 had. P4's PMP score increased from 9 to 49 using SPOOCI. He mastered the basic activities (score = 5), but going backward, serpentine, and variation in speed were difficult for him because of limitations of the pneumatic interface.

Participant 5

P5 was an undiagnosed adult man with a motor control pattern similar to cerebral palsy but good, though weak, forefinger-to-thumb opposition and good head control with gravity eliminated. P5 had never used powered mobility; his only method of mobility was being pushed in a manual wheelchair by a caregiver. P5 used eyeblink (yes) and head nod (no) for communication. P5 had fine distal movement of his fingers, but too fine to control the too-large pneumatic bulb. P5 tried SPOOCI with various body sites, including his feet, but had difficulty with excessive overflow movement. P5's head motor control was the least affected by spasticity with no overflow movement; embedding the pneumatic bulbs into a firm foam head support would have been optimal for P5, but that was beyond the scope of this study. Hand use would have been an option with a much smaller control interface. In spite of the challenges, P5's PMP score increased from 7 to 26 using SPOOCI; his basic skills increased from maximum to minimum assistance.

Discussion

This proof-of-concept study tested an innovative PW controller designed by an occupational therapist. Although the occupational therapist author (Winkler) had children with athetoid or dystonic cerebral palsy movement patterns in mind, the technology can be applied to many movement disorders and assistive devices (e.g., computers and alternative and augmentative communication devices). The PW controller tested in this study is worn by the user and requires two degrees of freedom of movement anywhere in the body, meaning that to use SPOOCI, two sources of independent movement must be identified: one to control forward and stop (and eventually backward) and the other to control right and left.

The success of this study was that the participants were able to use a worn device to drive and turn a PW. Less successful was the design of the interface, the pneumatic bulb. Simply stated, the bulb was too large and thus required a greater range of motion than the participants had. Participants could squeeze the bulb, but release and extension were problematic. Two SPOOCI prototypes will be pursued. One will be a smaller, cookie-sized sensor, and the other will use smart textiles (Berglin, 2013).

Implications for Occupational Therapy Practice

The results of this study have the following implications for occupational therapy practice:

- The fit and quality of the power wheelchair are critical to user independence and safety.
- Occupational therapists must evaluate posture and visual field when the user is seated in the wheelchair.
- Wireless technologies should provide options to reference the power wheelchair control interface to the wheelchair users' tone rather than requiring the user to adapt to the wheelchair-referenced joystick.

Conclusion

This proof-of-concept study demonstrates that an inexpensive PW control interface device worn by the user can be mastered by at least some people with severe motor impairment and with cause-and-effect cognitive skill. Further development is warranted to take the concept to a prototype and then to a commercially available product. ▲

Acknowledgments

We thank the families and clinicians who made this study possible. This research was supported by a Eunice Kennedy Shriver National Institute of Child Health and Development Award (R21HD053526). The patent US 8,244,655 B2 is owned by the University of Florida. The primary author, Sandra Winkler, is an inventor. There are no financial benefits to the authors. Aspects of this research have been presented as posters at the American Occupational Therapy Association Annual

Conference & Expo (April 2015) and the Florida Occupational Therapy Association annual conference (Fall 2014).

References

- Berglin, L. (2013). *Smart textiles and wearable technology—A study of smart textiles in fashion and clothing*. Borås, Sweden: University of Borås, Swedish School of Textiles.
- Fehr, L., Langbein, W. E., & Skaar, S. B. (2000). Adequacy of power wheelchair control interfaces for persons with severe disabilities: A clinical survey. *Journal of Rehabilitation Research and Development*, 37, 353–360.
- Furumasu, J., Guerette, P., & Tefft, D. (1996). The development of a powered wheelchair mobility program for young children. *Technology and Disability*, 5, 41–48. [http://dx.doi.org/10.1016/1055-4181\(96\)00146-X](http://dx.doi.org/10.1016/1055-4181(96)00146-X)
- Kooistra, B., Dijkman, B., Einhorn, T. A., & Bhandari, M. (2009). How to design a good case series. *Journal of Bone and Joint Surgery*, 91(Suppl. 3), 21–26. <http://dx.doi.org/10.2106/JBJS.H.01573>
- Palisano, R., Rosenbaum, P., Walter, S., Wood, E., & Galuppi, B. (1997). Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Developmental Medicine and Child Neurology*, 39, 214–223. <http://dx.doi.org/10.1111/j.1469-8749.1997.tb07414.x>
- Stewart, H., Noble, G., & Seeger, B. R. (1992). Isometric joystick: A study of control by adolescents and young adults with cerebral palsy. *Australian Occupational Therapy Journal*, 39, 33–39. <http://dx.doi.org/10.1111/j.1440-1630.1992.tb01733.x>