Upper Extremity Functional Improvements in Persons with SCI Resulted from Daily Utilization of Myoelectric Powered Wearable Orthotics

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Abstract— Spinal cord injury (SCI) is a medically complex and life-disrupting condition. It is estimated that 17,700 new traumatic SCI cases are reported each year in the United States. Approximately half of those cases, involves paralysis, sensory loss, and impaired motor control in the upper extremity (UE) and lower extremities.   Such impairments could affect the person's independence as well as their family members and caregiver. The limitation at the UE can significantly limit the general activities of daily living (ADL). The purpose of this paper is to determine the daily utilization effects on changing the handgrip AROM and handgrip forces before and after providing upper extremity in-clinic rehabilitation along with at-home utilization using an UE myoelectric powered wearable orthosis (UE-MPWO) in a person with incomplete spinal cord injury (iSCI). This device helps restore function to the weakened or paralyzed UE muscles. We demonstrate that the handgrip AROM and handgrip force improved after 6-weeks of training with the UE-MPWO. The overall goal of this study was to evaluate the effects of   UE-MPWO (MyoPro) when utilized for in-clinic rehabilitation combined with at-home daily use in improving UE movement and function of people with iSCI.

Clinical Relevance— The results of in-clinic rehabilitation combined with at-home daily utilization suggest that this UE-MPWO may improve UE function. The examined UE-MPWO could represent a relatively good example as a rehabilitation and assistive tool for persons with iSCI.

I. INTRODUCTION

Spinal cord injury is a medically complex and life-disrupting condition. An estimated incidence of 17,700 new traumatic SCI cases are reported each year in the United States [1]. In about half of those cases, the injury affects the cervical spinal cord, which leads to varying degrees of paralysis, sensory loss, and impaired motor control in the UEs and lower extremities. Impairments could affect the person's independence as well as their family members and care giver. The limitation at the UE can significantly limit the general activities of daily living (ADL) [2, 3]. The characteristics of the impairment depend on the extent and level of the SCI[4, 5]. Individuals with a higher level of SCI have limited capacity to move or perform basic activities of daily living (ADL). Such movement limitations significantly reduce a patient's quality of life (QOL) and level of independence, particularly when the UEs are impaired[6].

Restoration of UE motor function in people with SCI remains a **high priority in rehabilitation and in the field of assistive technology**. While there are many established rehabilitation technologies for strengthening and static splints to address contractures and tone management, there are only a few **wearable powered devices** developed specifically for increasing wrist/hand and elbow function to address these disabilities[6, 7]. Researchers have recently adopted task-specific methods for improving function and independence in individuals with SCI who have upper limb paralysis [2, 6, 7]. An example of this method is robotic assisted UE training for individuals with iSCI [8-10]. However, there is overall equivocal evidence for all those approaches on improving UE function especially wrist/hand and elbow function and activities of daily living (ADL) in this population. More importantly, most of the effective UE robotic assistive systems are not easily adapted outside research labs and clinical settings. This limits the utilization of such promising approaches for persons with SCI in the community and at home. To overcome such limitations, a promising approach involves a UE **wearable** robotic orthosis (UE-WRO) that can be used as a **therapeutic** tool in rehabilitation facilities or hospitals as well as at home **for assistance** during daily activities to improve independence with ADLs. A commercially available UE-WRO (MyoPro) manufactured by MyoMo, Inc. is such a device (Fig.1). This UE-MPWO (MyoPro) provides powered assistance for grasp and release and elbow flexion and extension based on the user's muscle activation. Major advantages of the MyoPro relative to other available UE-WRO systems include the light-weight in which can be worn and utilized anywhere (outside clinic, at home and in the community) and thus, can provide assistance needed for ADL such as feeding, carrying objects and doing household tasks[11]; the flexibility of the system control which is primarily determined by the by the user's intention, rather than preprogramed automated ones; this feature ensures that the user is voluntarily controlling the movements and is actively involved in making each movement, which is critically important for motor function recovery.. Powered assistance provided through this UE-WRO was controlled based on voluntary muscle activation signals detected by small sensors embedded within the UE-MPWO detect and amplify even weak transcutaneous nerve signals such as those

Figure.1. A myoelectric upper extremity orthosis (MyoPro)

in a patient with iSCI. Given the significant relationship between UE function and quality of life, independence, self-esteem, and community integration in individuals with neurological disability, rehabilitation modalities for the UE should serve to significantly improve multiple aspects of ADL [12, 13]. A promising device, such as the MyoPro, would be expected to improve everyday functioning and reduce the impact of injury/disease on the lives of individuals with neurological disorders. While robotic training is relatively a new approach and is developing day by day, several studies (mostly on stroke survivors [14-17]) have demonstrated the efficacy of UE-WRO across many domains of motor function and ADL. A case report on an individual with SCI demonstrated improvements in UE strength, tone management and ADL following UE-WRO utilization [18]. Another case report on individuals with SCI showed UE function improved after 4 weeks robotic assistance intervention. Manual muscle test scores for wrist extensors, finger flexors and finger abductors significantly increased[19]. Therefore, the overall goal of this study was to evaluate the effects of UE-MPWO (MyoPro) when utilized for in-clinic rehabilitation combined with at-home daily use in improving UE movement and function people with iSCI.

II. MATERIAL AND METHODS

A. UE Myoelectric Powered Wearable Orthotic used in this study(MyoMo)

The MyoPro (MyoMo Inc., Cambridge, Massachusetts) (Figure. 1) is a noninvasive, lightweight (approximately 4lbs), wearable system currently available in numerous rehabilitation facilities across the nation[14]. The orthosis provides 0 to 130 degrees of motion and 7 Nm of torque at the elbow and 1–2.7 Nm torque for the fingers. This translates into the ability to lift approximately 5–8 lbs. (depending on the user's clinical presentation)[14]. This orthotic device uses surface electromyography (sEMG) signals from affected muscle groups to control a powered orthosis, providing powered assistance for elbow flexion and extension and gross grasp motions via motors attached to the exterior of the brace. It functions by continuously monitoring the sEMG signals of the user's bicep and triceps muscles for elbow motion and the forearm flexor and extensor muscle groups for grasp motion (a 3 jaw-chuck grip pattern). These signals are filtered and processed on-board of the MyoPro device to provide a desired joint torque proportional to the exerted effort of the user. This allows even small EMG amplitudes (EMG traces) to be magnified to produce joint motion with assistance provided by the device's motors at the elbow and hand.

B. In-clinic training provided using the UE-MPWO (UE orthosis, MyoMo)

After baseline assessment was completed, the participant received a MyoPro orthotic device to utilize during ADL at home/community for the duration of the study (6 weeks). The participant was asked to follow a home activity plan (use as much as possible) and a wearing schedule (beginning at 1 hour daily) to increase endurance and facilitate functional use of her extremity while using the orthosis. Refinements of the home activity program was done as recommended by the treating therapist and based on the patient's proficiency in utilization the device. Home activity program included meaningful functional tasks, such as: Practicing donning/doffing of the orthotic device, practicing repetitive task drills, and applying multistep functional tasks while using the orthosis (i.e., hand to mouth movement tasks, holding an object and releasing it, and practicing the ability to extend their arm, operate light switches, and practicing the ability of scratching/touching her face). It is important to note that the participant, even while using the orthosis in the first week, was unable to accomplish some of these functional tasks, but the initiation of doing these tasks is crucial to ensure improvements on motor function and the relearning process.

C. Experimental Procedure

1) Subjects
The data analyzed in this paper consist of active handgrip angular position, and handgrip force from a 22-year-old female with SCI (ASIA Impairment Scale (AIS) C, level C6-C7).

2) Baseline and post-training evaluations.
Data collection in the evaluation sessions started by having subjects seated in their powered wheelchair and testing was administered without the UE-MPWO (Figure. 2). Each hand's activities were evaluated using a customized system including a 9-axis Absolute Orientation Inertial Measurement Units (IMU) sensor (Adafruit Bosch Sensortec, USA) for measuring hand angular position; a 1-DOF load sensor (Load Cell (0-20kg), Calgary, Canada) for measuring handgrip forces; and 2-channels of EMG measured by Brain Products amplifier, Munich- Germany).

The IMU sensor was attached to the distal end of participants' hand using Velcro straps on the hands four fingers (without the thumb). Participants' hands were attached to the force sensor grippers at the palm using Velcro while keeping the hand's four fingers free to open and close (handgrip motion). Participants sat approximately 60cm from a monitor that displayed visual cues during testing trials. Testing started by displaying two red "X" letters representing each hand. The red "X" was the visual cue for opening the hand. Next, a green "O" either appeared on the right or left side of the screen. This visual cue prompted the participant to maximally grasp (close their hand) the force sensors and hold while the green letter
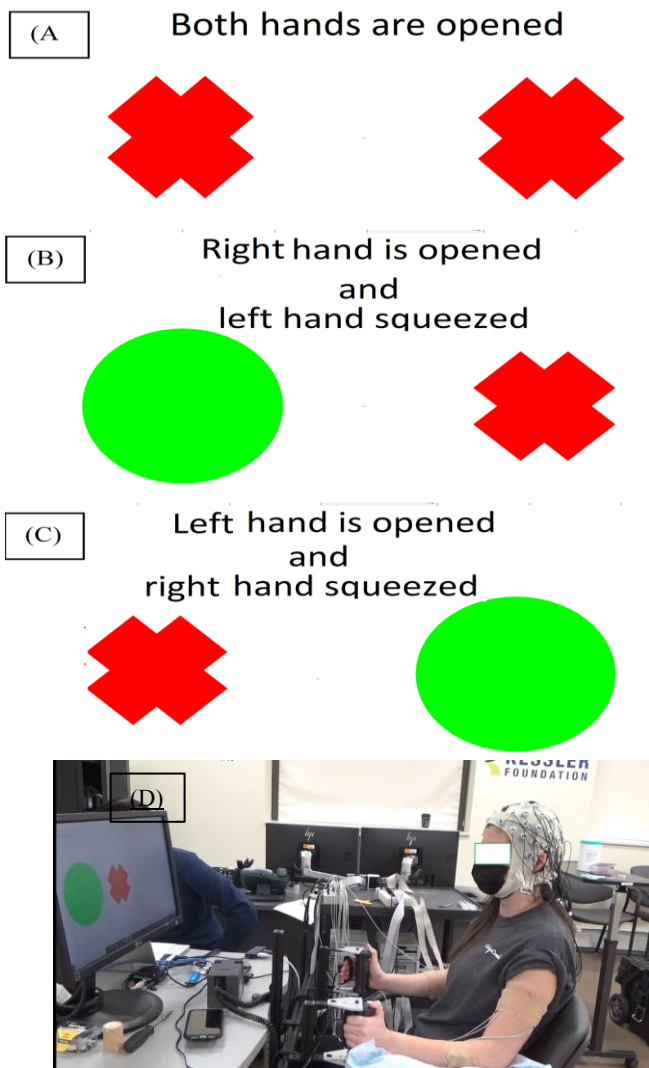
Figure 2. Visual cues presented to participants during this evaluation. (A) two red X, cue participants to open both hand and relax. (B) left green circle and right red X cue the participant to squeeze their left hand and keep their right hand opened. (C) right green circle and left red X, cue the participants to squeeze their right hand and keep their left hand opened. (D) The participant while in the evaluation session.

was displayed. After that two red "X" letters were displayed cueing the participants to open the hand which was in motion. An additional 29 green cues (totaling 15 for each side) were randomly repeated. Each green cue lasted for 4 seconds before it changed to a red cue. Red cues were displayed for a time randomly generated (ranges between 2.3 -4.3 seconds to eliminate learning factors).

3) Data Analysis

A custom script using MATLAB 2020 (The MathWorks, Inc) was created to analyze the collected data. The hand angle-position and handgrip force measurements were filtered using a bidirectional zero-lag Butterworth low-pass filter (cutoff frequency= 10Hz) . *Data was segmented to include 15 grasp motions for each hand. Each handgrip was*

normalized to 100% activity cycle starting at 0% (when a motion cue (green circle) was presented to participants) and 100% (when the presented cue becomes a red X) (Figure 2).

III. RESULTS

1) Data outcomes

Data on handgrip angle, and handgrip force are presented in Table 2 and Figure 3. These data are the results of evaluation at baseline (prior to using the UE-MPWO) and post 6-weeks of training using the UE-MPWO.

2) Biomechanical outcomes

The participants received 18-training sessions in a rehabilitation research center (similar to an outpatient therapy gym), 3 times per week (1hour/session) using the UE-MPWO. Each session was closely supervised by a licensed therapist and involved a customized level of training and assistance using the UE-MPWO device. Further, the participant continued to utilize the UE-MPWO at home during her daily life activities. The participant demonstrated
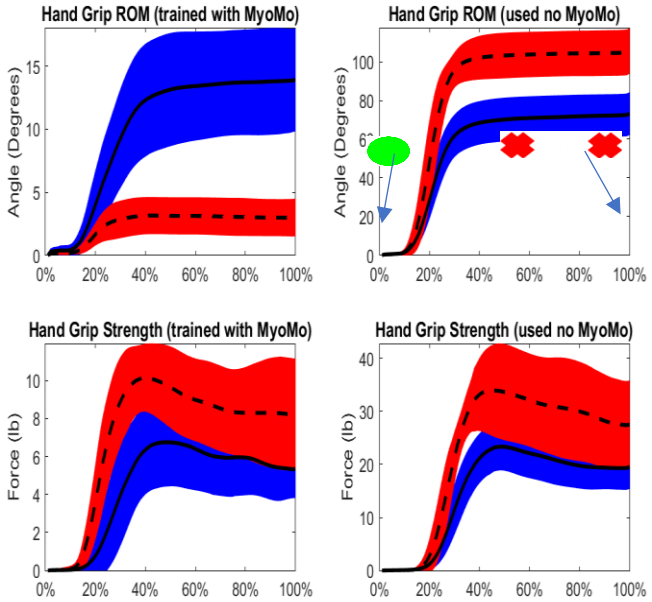

Figure 3. Data representation of a participant with SCI collected during handgrip squeeze evaluation at baseline and post 6-weeks of UE-MPWO training.
(left column) represents the data from the side that received the UE-MPWO training. (right column) represents data collected from the hand did not receive UE-MPWO.
Red plots represent post 6-weeks of training and blue represent baseline data.
The x-axis percent represents the instance when a motion cue (green circle) was presented to the participant on either the right or left side (0%), and when the presented cue becomes a red X on both sides, the squeezing task is completed and concludes one sequencing activity cycle at 100%.

a large improvement in hand handgrip tasks post-MPWO training compared to baseline (i.e. without the MPWO, while the AROM of the hand trained in the MyoPro was reduced at post training compared to baseline -due to experiencing

excessive level of spasticity there was large improvements in handgrip force during the handgrip tasks at post-training compared to baseline for both UEs trained with and without MPWO) (Figure 3).

3) Motor control and physiological outcomes

The handgrip AROM and forces outcomes were synchronized during the evaluation. Post- training there was a large increase in the handgrip AROM on the right side (although not training with UE-MPWO) and there were large increases of handgrip force (bilaterally, the side trained with UE-MPWO and the other one which didn't receive training using the UE-MPWO)

IV. Discussion

Overall, applying the UE-MPWO condition was successful in this participant with iSCI with no series adverse event during the trial. The large increase in the handgrip AROM (on the right side) and great improvement of the handgrip force (bilaterally) after receiving in-clinic UE-MPWO training for 6-weeks and utilizing the UE-MPWO at home may be considered as a result of improved UE motor control caused by the repeated robotic assistance provided by the UE-MPWO. These improvements were not only limited to the UE that received training with the UE-MPWO, but also the other UE (i.e., without utilizing UE-MPWO) also improved as represented by the increased handgrip forces (Figure 3.B). This may be the result of actively engaging both UEs during functional activities eventually results in such motor control and biomechanical improvements. In addition, the improvements in handgrip AROM and forces during the handgrip tasks were also associated proportionally with changes in the response time to the gripping cue presented to the participant. The response time needed to initiate the grasp motion was improved (decreased), as indicated on Figure 3.

We further notice that there is some variability in the outcome measurements of handgrip forces and AROM as indicated by the shaded area (in blue and red) on Figure 3. These variations are expected from persons with SCI [20, 21]. Data analysis of a larger sample is underway to confirm the findings.

V. Conclusions

Data in this pilot case report show the effects of daily utilization of an UE-MPWO device by comparring results from baseline assessment and post 6-weeks of training and home-utilization. Improvements were not limited to the UE that received UE-MPWO training, but also indirectly improved the UE that did not receive UE-MPWO training. It is possible that participants were able to perform bi-manual tasks largely while utilizing the device. In general, the improvements in handgrip AROM and forces may further increase the independence with ADL and functional tasks, especially when UE-MPWO is used more regularly for a prolonged duration.

Acknowledgment

[1] S. C. I. Facts, "Figures at a Glance. 2012," *J. Spinal Cord Med,* vol. 37, pp. 479-480, 2017.

[2] R. Martin and J. Silvestri, "Current Trends in the Management of the Upper Limb in Spinal Cord Injury," *Current Physical Medicine and Rehabilitation Reports,* vol. 1, no. 3, pp. 178-186, 2013.

[3] N.-H. White and N.-H. Black, "Spinal cord injury (SCI) facts and figures at a glance," 2016.

[4] W. H. Organization and I. S. C. Society, *International perspectives on spinal cord injury.* World Health Organization, 2013, p. 3.

[5] M. J. Kuipers, "Functional Electrical Stimulation as a Neuroprosthesis for Sitting Balance: Measuring Respiratory Function and Seated Postural Control in Able-bodied Individuals and Individuals with Spinal Cord Injury," University of Toronto (Canada), 2013.

[6] P. Maciejasz, J. Eschweiler, K. Gerlach-Hahn, A. Jansen-Troy, and S. Leonhardt, "A survey on robotic devices for upper limb rehabilitation," *Journal of neuroengineering and rehabilitation,* vol. 11, no. 1, p. 3, 2014.

[7] S. Hesse, H. Schmidt, C. Werner, and A. Bardeleben, "Upper and lower extremity robotic devices for rehabilitation and for studying motor control," *Current opinion in neurology,* vol. 16, no. 6, pp. 705-710, 2003.

[8] K. D. Fitle, A. U. Pehlivan, and M. K. O'Malley, "A robotic exoskeleton for rehabilitation and assessment of the upper limb following incomplete spinal cord injury," in *Robotics and Automation (ICRA), 2015 IEEE International Conference on*, 2015: IEEE, pp. 4960-4966.

[9] J. M. Frullo *et al.*, "Effects of assist-as-needed upper extremity robotic therapy after incomplete spinal cord injury: a parallel-group controlled trial," *Frontiers in neurorobotics,* vol. 11, 2017.

[10] D. Vanmulken, A. Spooren, H. Bongers, and H. Seelen, "Robot-assisted task-oriented upper extremity skill training in cervical spinal cord injury: a feasibility study," *Spinal Cord,* vol. 53, no. 7, p. 547, 2015.

[11] M. I. USA, "Returning Veterans to Arm Mobility and Independence." [Online]. Available: http://myomo.com/veterans/#veterans-learn-more.

[12] B. Ozcan *et al.*, "Relationship between daily life activities and upper extremity exercise capacity in patients with pulmonary arterial hypertension," ed: Eur Respiratory Soc, 2015.

[13] C. Rudhe and H. J. van Hedel, "Upper extremity function in persons with tetraplegia: relationships between strength, capacity, and the spinal cord independence measure," *Neurorehabilitation and Neural Repair,* vol. 23, no. 5, pp. 413-421, 2009.

[14] S. Dunaway, D. B. Dezsi, J. Perkins, D. Tran, and J. Naft, "Case Report on the Use of a Custom Myoelectric Elbow–Wrist–Hand Orthosis for the Remediation of Upper Extremity Paresis and Loss of Function in Chronic Stroke," *Military Medicine,* vol. 182, no. 7, pp. e1963-e1968, 2017.

[15] G. J. Kim, L. Rivera, and J. Stein, "Combined clinic-home approach for upper limb robotic therapy after stroke: a pilot study," *Archives of physical medicine and rehabilitation,* vol. 96, #. 12, pp. 2243-2248, 15

[16] H. T. Peters, S. J. Page, and A. Persch, "Giving Them a Hand: Wearing a Myoelectric Elbow-Wrist-Hand Orthosis Reduces Upper Extremity Impairment in Chronic Stroke," *Archives of Physical Medicine and Rehabilitation,* 2017.

[17] N. W. Willigenburg, M. P. McNally, T. E. Hewett, and S. J. Page, "Portable Myoelectric Brace Use Increases Upper Extremity Recovery and Participation But Does Not Impact Kinematics in Chronic, Poststroke Hemiparesis," *Journal of motor behavior,* vol. 49, no. 1, pp. 46-54, 2017.

[18] M. Cabell, "Poster 217: Case Report on the use of Bilateral Myoelectric Elbow-Wrist-Hand Orthoses for the Remediation of Upper Extremity Paresis following a Spinal Cord Injury," *PM&R,* vol. 9, no. 9, p. S201, 2017.

[19] N. Yozbatiran *et al.*, "Robotic training and clinical assessment of upper extremity movements after spinal cord injury: a single case report," *Journal of rehabilitation medicine,* vol. 44, no. 2, pp. 186-188, 2012.

[20] L. C. Nacul, K. Mudie, C. C. Kingdon, T. G. Clark, and E. M. Lacerda, "Hand grip strength as a clinical biomarker for ME/CFS and disease severity," *Frontiers in neurology,* vol. 9, p. 992, 2018.

[21] R. Barański and A. Kozupa, "Hand Grip-EMG Muscle Response," *Acta Physica Polonica, A.,* vol. 125, 2014.