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The Rehabilitation Effects of Myoelectric Powered Wearable Orthotics on Improving Upper Extremity Function in Persons with SCI

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Abstract— **Upper extremity (UE) weakness and/or paralysis following spinal cord injury (SCI) can lead to a limited capacity to perform activities of daily living (ADL). Such disability significantly reduces an individual's level of independence. Further, restoration of UE motor function in people with SCI remains a high priority in rehabilitation and the field of assistive technology. The overall goal of this study was to evaluate the effects of a myoelectric-powered wearable orthosis (MPWO) manufactured by MyoMo, Inc. (Boston, MA) for UE movement assistance on ameliorating UE motor function in order to improve ADL and quality of life in people with SCI. Two male participants with chronic incomplete SCI (iSCI), a 75- and a 31-year-old with AIS D and B, respectively, underwent 18 sessions (over 6 weeks) of UE movement rehabilitation using the MPWO. Handgrip strength, active range of motion (AROM) of the hand, response time to initiate a movement, and muscles activations were examined before and after the rehabilitation training using the MPWO. The response time to initiate UE movements decreased, and handgrip strength and AROM improved after training with the MPWO. These preliminary data suggest that rehabilitation with the use of the UE-MPWO device could enhance the participants' UE activities that led to improved function.**

***Clinical Relevance*— These preliminary results from two individuals with iSCI suggest that training with UE-MPWO assistive devices may improve UE utilization during ADL for individuals with muscle weakness or paralysis but still possessing residual voluntary muscle activation capabilities.**

I. INTRODUCTION

Spinal cord injury (SCI) is a medically complex and life-disrupting condition. An estimated incidence of 17,900 new traumatic SCI cases are reported each year in the United States [1, 2]. In about half of these cases, the injury affects the cervical spinal cord, which leads to varying degrees of paralysis, sensory loss and impaired motor control in the upper and lower extremities (UEs & LEs). These impairments can cause significant disability and dependence for functional activities [3, 4]. The characteristics of the impairment depend on the extent and level of the SCI [5, 6]. Individuals with a higher level of spinal cord injury (e.g. upper cervical section) have limited capacity to move or perform basic UE 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 [7]. 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 muscle strengthening and a number of static splints are available 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 UE disabilities [7, 8]. Researchers have recently adopted task-specific methods for improving function and independence in individuals with SCI who have upper limb paralysis [3, 7, 8]. An example of this method is robotic assisted UE movement training for individuals with incomplete SCI (iSCI) [9-11]. However, there is overall equivocal evidence for all of those approaches on improving UE function especially wrist/hand and elbow function and activities of daily living (ADL) in this population. Further, such interventions are not easily adapted

Figure.1. Illustration of the myoelectric upper extremity MyoPro MPWO described in the text

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outside research labs and clinical settings, and thus, do not provide ADL assistance. To overcome such limitations, a promising, commercially available technology, myoelectric-powered wearable orthosis (MPWO) (MyoPro, MyoMo Inc., Boston MA) that is designed to assist UE motor function has been used as a therapeutic tool in rehabilitation facilities as well as at home for finger, wrist and elbow joint movement assistance during daily activities to improve independence with ADL (Fig.1). This MyoPro UE-MPWO provides powered assistance for grasp and release, and elbow flexion and extension triggered by the user's residue voluntary muscle activities. Powered assistance provided through this UE-MPWO is controlled by residue voluntary muscle activation signals detected by small sensors embedded within the UE-MPWO. The system is able to detect and amplify weak muscle electric signals such as those in weakened muscles in individuals with iSCI. Major advantages of the MyoPro MPWO relative to other available UE wearable robotic orthosis (WRO) systems are that: (i) it is relatively light-weight and can be worn outside of clinical settings and thus, can provide assistance needed for ADL such as feeding, carrying objects and performing household tasks [12]; (ii) its movements are controlled and guided by the user's intention, rather than preprogramed automated ones; (iii) by voluntarily controlling the movements, the patient is actively involved in making each action, which is critically important for motor function recovery and re-establishing the sensorimotor pathways; and (iv) it is specifically designed for assisting wrist/hand and elbow movements (many cervical SCI and stroke patients have wrist/finger movement disabilities and these lost functions are difficult to recover). Given the significant relationship between UE function and quality of life, independence, self-esteem, and community integration in individuals with neurological impairments, rehabilitation modalities for the UE should serve to significantly improve multiple aspects of ADL [13, 14]. The MyoPro MPWO is designed and intended to improve everyday UE functioning and reduce the impact of injury/disease on the lives of individuals with neurological disorders. While robotic training is a new approach and is developing day by day, several studies (mostly on stroke survivors [15-18]) have demonstrated the efficacy of UE MPWO 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 MPWO utilization [19]. 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 abductors significantly increased [20]. Our current study provided unique set of objective assessment outcomes combining ROM with EMG measurements which allowed us to comprehensively evaluate any changes results in providing this intervention. Therefore, the overall goal of this study was to evaluate the effects of UE MyoPro MPWO on ameliorating UE movement impairments in order to improve ADL and quality of life in people with iSCI.

II. Material and Methods

A. Subjects

The data analyzed here consists of active handgrip angular position, handgrip force, and finger flexor and extensor sEMG from a 75-year-old male with iSCI (ASIA Impairment Scale (AIS) D, level C4, 29 months post injury) and a 31-year-old male with iSCI (ASIA Impairment Scale (AIS) B, level C6, 72 months post injury).

B. Experimental Procedure

1) Training provided using the MyoPro UE-MPWO

The participants received 18-training sessions in a rehabilitation research center (similar to an outpatient therapy gym), three times per week (~60 min/session) using the MyoPro 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.

The MyoPro UE-MPWO (Figure. 1) is a noninvasive, lightweight (approximately 4lbs), wearable system currently available in numerous rehabilitation facilities across the nation [15]. The powered 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 up to 8 lbs for elbow flexion [15]. The, MyoPro UE-MPWO system uses surface electromyography (sEMG) signals from the affected muscle groups to control the powered orthosis, providing 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 biceps and triceps muscles for elbow motion and the finger flexor and extensor muscle groups in the forearm for grasp motion (a 3 jaw-chuck grip pattern). The sEMG signals were filtered and processed on-board of the MyoPro MPWO to provide a desired joint torque proportional to the exerted effort of the user. This allowed 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.

2) Baseline and post-training evaluations.

Data collection in the evaluation sessions started by having subjects seated in their powered wheelchair and the testing was administered without wearing the UE-MPWO (Figure. 2). Measurements for each hand were made 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 sEMG together with Brain Products amplifiers (Munich- Germany) for measuring the finger flexor and extensor activities.

The IMU sensor was attached to the distal end of participants' hand (i.e., close to the fingertips) using Velcro straps on the four fingers (without the thumb). Participants' hand was attached to the force sensor gripper at the palm using a Velcro strap while keeping the hand's four fingers free to open and close (handgrip motion).

One EMG electrode was placed on the flexor digitorum superficialis (flexor muscle), and another EMG electrode was placed on the extensor digitorum (extensor muscle). Of note, these are similar locations to where the MyoPro's forearm electrodes are placed while utilizing it to assist in hand-grip motion. Prior to electrode placement, a sponge and alcohol swab cleansed the skin.

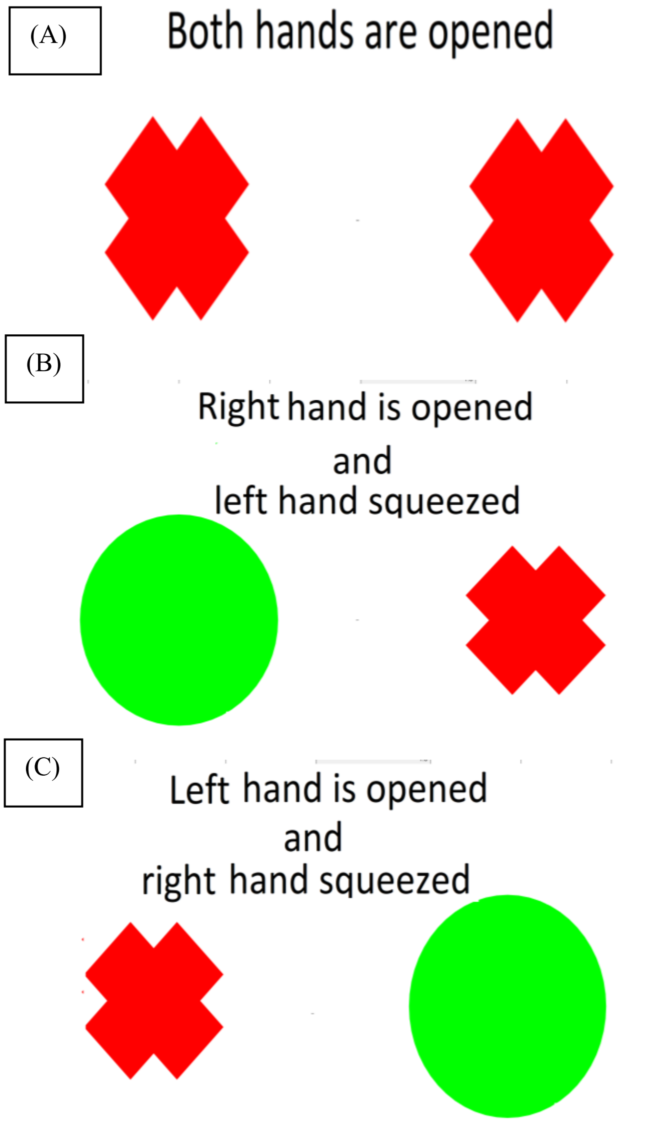

Figure 2. Visual cues presented to participants during pre- and post-training evaluations. (A) two red X, cue participants to open both hand and relax. (B) left green circle and right red X cue the participant to squeeze their left hand and keep their right hand opened. (C) right green circle and left red X, cue the participants to squeeze their right hand and keep their left hand opened.

Participants sat approximately 60 cm 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 was displayed. After that two red "X" letters were displayed cueing the participants to open the hand which was in motion. A total of 30 green cues (15 for each side) were randomly presented. Each green cue lasted for 4 seconds before it changed to a red cue. Red cues were displayed for a random duration (ranges between 2.3 -4.3 seconds to minimize the learning effect).

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) and EMG data were filtered and rectified using a bidirectional zero-lag Butterworth band-pass filter (cutoff frequency= 10-350Hz) and then the envelope was generated to represent a clear muscle activation during the testing activities.

The data were 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

Overall, applying the UE-MPWO for the UE movement training was successful in the participants with iSCI with no adverse event during the study.

1) *Outcome measures*

Data on handgrip angle, handgrip force and sEMG from the finger flexor and extensor muscles that squeezed and opened the hand, respectively are presented in Table 2 and Figure 3. These data are the results of evaluation at baseline (prior to the trainijng using the UE-MPWRO, blue color in Fig. 3) and post 6-weeks of training using the UE-MPWO (red color in Fig. 3).

2) *Biomechanical outcomes*

On average, the participants demonstrated a large improvement in hand AROM during the handgrip tasks post-MPWO training compared to baseline (i.e. on average, without the MPWO. The AROM of the hand trained in the MyoPro was 1.1^{o} at baseline assessment and 9.6^{o} post training and 8.02^{o} at baseline and 9.50^{o} post training on the other hand) (Figure 3 and Table 2).

Table 1. Participant characteristics.

Subject	**Gender**	**Age -year**	**SCI level**	**AIS Classification**	**Months post injury**
1	Male	75	C4	D	29
2	Male	31	C6	B	72

Further, there was a large improvement in handgrip strength during the handgrip tasks at post-training compared to baseline for both UEs trained with and without UE-MPWO.

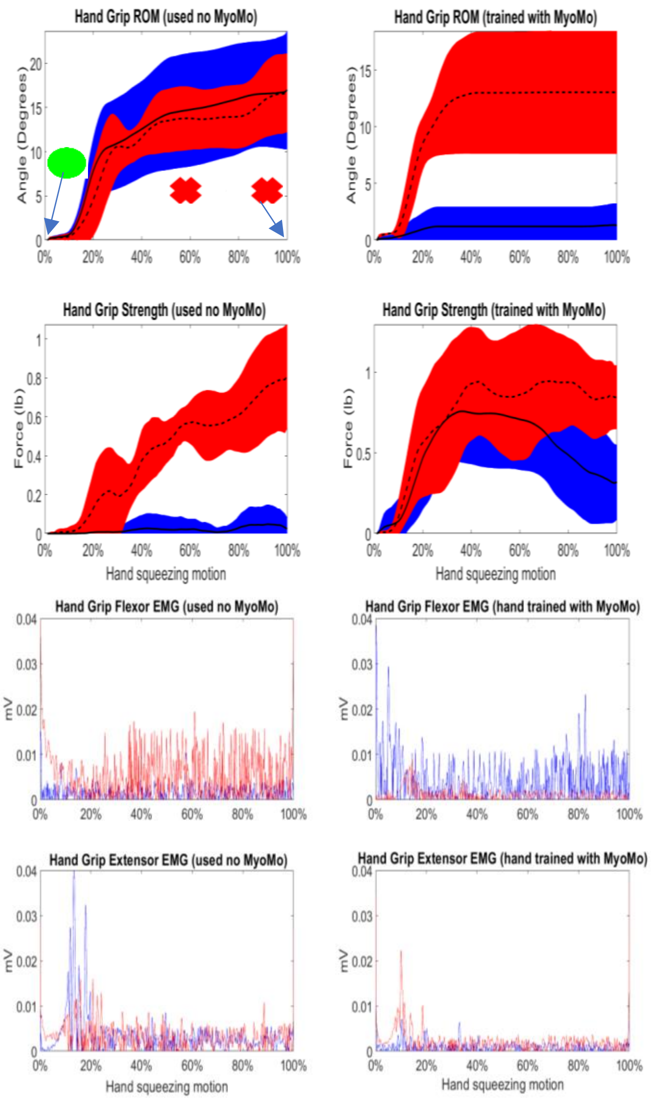

Figure 3. Data representation of a participant with iSCI collected during handgrip squeeze evaluation at baseline and post 6-weeks of training using the MyoPro UE-MPWO device.
Left column represents the data from the side that did not receive the UE-MPWO training. Right column represents data collected from the hand trained using the UE-MPWO.
Red plots are representing post 6-weeks of training and the blue plots are representing baseline.
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%.

3) Motor control and physiological outcomes

The handgrip AROM and force outcomes were synchronized with the sEMG data from the agonist and antagonist muscles associated with the handgrip task during the evaluation.

Table 2. Handgrip data collected at baseline and post-training.

Subject			**1**	**2**	**Average**
Baseline	The side used UE-MPWO	AROM	1.00	1.20	1.10
		Force	0.02	0.75	0.39
	The side with no use of UE-MPWO	AROM	0.04	16.00	8.02
		Force	0.01	0.04	0.03
Post	The side used UE-MPWO	AROM	6.20	13.00	9.60
		Force	0.77	0.95	0.86
	The side with no use of UE-MPWO	AROM	2.40	16.60	9.50
		Force	0.06	0.79	0.42

Post- training, there was an altered pattern of EMG amplitude combined with the increase in handgrip force and AROM, and a decreased response-time measured by determining the time difference between onset of the EMG and beginning of the movement of the hand (i.e., the starting of the hand motion) compared to the response time at the baseline (Figure 3).

I. Discussion and Conclusions

The large increases in the handgrip AROM and handgrip strength on the UE that received the MyoPro UE-MPWO training for 6-weeks may be considered as the result of improved UE motor control caused by the users' intention-induced repeated robotic assistance provided by the UE-MPWO. It has been shown that voluntary effort/intention plays a significant role in determining muscle output following a motor training program [21]. The observed improvements were not limited to the UE that received training with the UE-MPWO. The other UE (without the MPWO training) also improved the handgrip strength (Figure 3.A). The strength increase in the untrained limb may be explained by the well-known cross-training or cross-education" effect, in which voluntary activation of one side of the brain during training of the contralateral limb extends its influence to the other side through interhemispheric connections [22]. Additionally, this cross-training effect may partially be due to increased actively engaging both UEs during functional activities in daily living during the training period, eventually resulted in the motor performance improvements in the untrained limb.

In addition, the improvements in handgrip AROM and strength during the handgrip tasks were also associated proportionally with the sEMG signals recorded from the agonist (flexor) and antagonist (extensor) muscles used for grasp (Figure 3). The response time needed to initiate the grasp motion was improved (decreased), as indicated by the arrows on Figure 3.

We further notice that there is some variability in the outcome measurements of the 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 [23, 24].

II. Conclusions

UE movemernt training using the MyoPro UE-MPWO imprpoves handgrip active range of motion, handgrip strength, and EMG activation of the handgrip muscles. These improvements were not limited to the UE that received the UE-MPWO training, but they also occurred on the UE that did not receive UE-MPWO training most likely because of the cross-training or cross-education effect. Larger trials need to be conducted to confirm the preliminary data of this study.

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