2011 IEEE International Conference on Rehabilitation Robotics
Rehab Week Zurich, ETH Zurich Science City, Switzerland, June 29 - July 1, 2011

Use of an Electromyographically Driven Hand Orthosis for Training after Stroke

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Abstract - **A pilot study was conducted to test the feasibility of using electromyographic signals to drive an active orthosis for hand therapy after stroke. Five stroke survivors with chronic hemiparesis completed 18 one-hour training sessions over 6 weeks. Activation patterns of a long finger flexor muscle and a long finger extensor muscle controlled an orthosis, the J-Glove, which provided assistance to finger extension to facilitate grasp-and-release movements. Initial results showed improvement in performance on one component, lifting a can, of the Wolf Motor Function Test for every subject and on the Action Research Arm Test for three of the subjects. Excitingly, a couple of the subjects showed signs of improved muscle activation patterns, although this requires further investigation.**

Keywords-stroke, hand, electromyography, orthosis

I. INTRODUCTION

Humans interact with their environment primarily through their hands. Unfortunately, hand impairment is common after stroke, one of the leading causes of major, long-term disability [1]. More than 6 million stroke survivors reside in the U.S. alone [1], and roughly half of these individuals have chronic deficits in upper extremity control [2].

While a number of factors contribute to the hand impairment, a fundamental issue is the difficulty in generating appropriate muscle activation patterns. Excessive coactivation [3] and lack of modulation of activation patterns with task [5] are often present.

Repetitive training of appropriate tasks in some has been shown to lead to changes in cortical activation patterns in some stroke survivors [6]. Additionally, visual feedback of fingertip force direction during training of a pinching task led to improved hand motor performance in chronic stroke survivors [7]. Unfortunately, many stroke survivors do not possess adequate control of the hand to perform repetitive task practice. Digit extension, necessary both to position the hand for grasp [8] and to release the grasped object, is especially problematic [9].

Thus, we have developed an instrument, termed the J-Glove, to provide active assistance of digit extension to facilitate practice of grasp-and-release tasks. The device monitors electromyographic (EMG) signals, both to ensure active participation of the user and to provide feedback of EMG patterns to the user. We performed a pilot study with 5 stroke survivors to determine whether training with this EMG-driven device could help to alter abnormal activation patterns. The initial results show promise, but further investigation is needed.

II. METHODS

A. Participants

Table I. Characteristics of the stroke survivors. (n=5)

Subject	Age(Yrs)	Gender	Time Post-Stroke(Years)	Impaired Side	Handedness	(CMSA)
1	66	M	7	L	R	4
2	45	M	12	L	R	4
3	80	M	5	L	R	4
4	70	F	21	R	R	4
5	51	F	6	R	R	4
Mean ± SD	62 ± 14		10 ± 7			

Note: *SD* = standard deviation; CMSA= Chedoke McMaster Stroke Assessment; M = male; F = female; L = left; R = right.

Five subjects with chronic hemiparesis resulting from stroke were asked to complete a pilot training study focused on practice of grasp-and-release tasks. Each subject had experienced a stroke at least 6 months prior to enrollment in the study (see ***Table I***) and had moderate hand impairment, classified as Stage of Hand 4 on the Chedoke-McMaster Stroke Assessment (CMSA) scale [10]. Subjects were able to generate some voluntary activity in a long finger extensor muscle, *extensor digitorum communis* (EDC) and in a long finger flexor muscle*, flexor digitorum superficialis* (FDS), in accordance

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This work was supported by the following grants from the National Institute on Disability and Rehabilitation Research (H133E070013 – Rehabilitation Research Center and H133F090018 – Mary E. Switzer Fellowship).

978-1-4244-9861-1/11/$26.00 ©2011 IEEE

with their rating on the CMSA. The Institutional Review Board of Northwestern University approved the experimental protocol and participants provided informed consent prior to enrollment in the study.

B. Protocol

Subjects completed 3 one-hour training sessions each week for 6 weeks, yielding a total of 18 sessions. During each session, the subject was asked to practice sets of grasp-and-release tasks while wearing an assistive hand orthosis, termed the J-Glove [11]. The stroke survivor attempted to grasp objects of different shapes and sizes (such as balls, cans, and utensils), transport them, and then release them at the appropriate position. Ten different initiation and termination target sights were specified to encourage movement throughout the workspace (see ***Figure 1).*** The user controlled the active orthosis through electromyographic (EMG) signals recorded from EDC and FDS. Namely, relative magnitudes of the EDC and FDS signals with respect to threshold values determined the action of the glove. Real-time feedback of the magnitudes of FDS and EDC were provided to the participants on a computer screen.

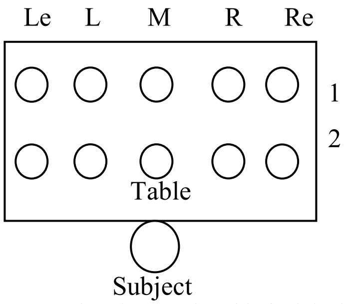

Figure 1. Different target locations on the table for initating and terminating object transport, L and R corresponds to the left and right shoulder of the subject. For example, the subjects may have been instructed to grasp a ball at position L2 and release it at position M1.

C. Evaluation

Clinical evaluations of upper extremity performance were conducted prior to and following the 6-week training program. A research occupational therapist recorded time to properly perform a subset of tasks from the Wolf Motor Function Test (WMFT) with the impaired upper limb [12]. The 6 components were chosen because they required grasp and manipulation of objects. The Action Research Arm Test (ARAT) was also used to assess upper extremity motor control [13]. Changes in activation patterns were assessed by looking at EDC and FDS EMG magnitudes during the 1st and 18th training sessions. EMG signals were rectified and then low-pass filtered to create envelopes which served as measures of magnitude.

D. J-Glove Description

The J-Glove is a cable-driven orthosis worn as a glove by the user (Fig. 2a). Five cables run across the back of the 5 digits through chains of custom-fabricated cable guides. Force in the cable is transmitted to the finger through the cable guides and the glove, thereby inducing extension torques at the joints. These five cables run together to form a single cable at the wrist. This single cable runs through a Bowden cable to a servomotor (1724 DC-Micromotor, Gearhead 134:1, Encoder IE2-16; Faulhaber, Inc.) mounted on a custom box (Fig. 2b). The servomotor is controlled via pulse-width modulation (PWM) signals from a Rabbit microprocessor (RCM 4510, Digi International, Inc., Davis, CA) programmed with the software Dynamic C (Digi International, Inc., Davis, CA). The microcontroller is located inside the box.

Feedback of cable length is calculated from the encoder connected to the servomotor. Motor rotation is converted into cable displacement. Limits of hand opening (digit extension) and hand closing (digit flexion) are signaled through buttons located on the box. Cable tension is transduced with a custom in-line tension sensor utilizing a cantilevered beam instrumented with strain gauges (Model # SGD-1.5/120-LY11). Processing of the signals from the tension sensor and from the passive EMG electrodes is performed on custom printed circuit boards, prior to sampling by the microcontroller.

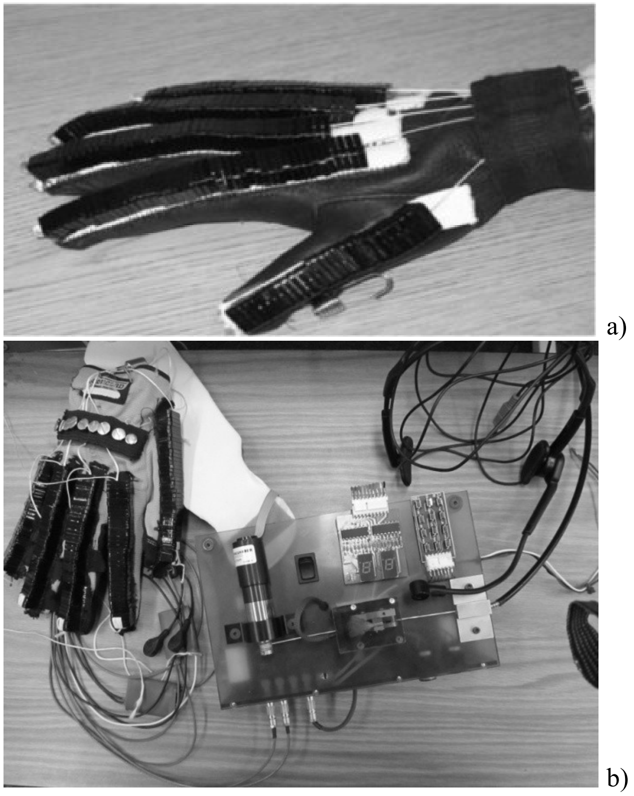

Figure 2. a) Cable-driven orthosis worn as a glove by the user. The black plastic pieces are the custom-fabricated cable guides. b) J-Glove components. The Bowden cable connects to a servomotor which drives the glove. All electronics are located in the single box.

The program code has two states, opening and closing. The starting state is set to opening: the hand of the user is closed and the microprocessor waits for the EDC muscle activity to go beyond a voltage threshold, which is modified in each session depending on subject muscle activity. Once the threshold has been achieved, the RCM 4510 set a pulse-with modulation (PWM) signal to active, and then the motor pulls the cables in steps of 10% of the total range of motion, therefore users are required to activate their muscles continuously until the extension limit is reached. Once the extension limit is achieved, the microcontroller automatically switches the algorithm to the closing state, and it lets the user close the hand step by step if the set threshold is been exceeded by the FDS muscle, until the flexion limit is reached, and then the program switch to the original opening state, completing one movement cycle.

III. RESULTS

Five adult participants completed the 18 training sessions. Performance on the ARAT and WMFT was evaluated before and after the training. Average values and standard deviations for measurements are presented in **Table II**.

Although some participants demonstrated increases in completion time for some tasks of the WMFT (***Figure*** 3, **Table III**), all subjects showed a reduction in the time required to perform the task Lift Can. Mean time for task completion decreased from 23.9 seconds pre-training, to 9.0 seconds post-training, demonstrating a 14.9 second decrease (***Figure*** 4).

Table II. Group of values for pre and post training.

Evaluation & Subject		
	Mean ± SD (Seconds)	Mean ± SD (Seconds)
WMFT Time	**Pre**	**Post**
1	14.6 ± 9.4	14.4 ± 8.9
2	24.8 ± 17.6	52.3 ± 54.9
3	10.9 ± 9.0	14.4 ± 11.2
4	88.4 ± 50.7	65.1 ± 60.2
5	18.6 ± 28.2	13.4 ± 14.6
ARAT		**Total ARAT Score(Max Score 57)**
	Pre	**Post**
1	17	20
2	34	31
3	28	31
4	15	15
5	40	47

Note: *SD* = standard deviation; WMFT = 6 tasks of the Wolf Motor Function Test; ARAT = Action Research Arm Test.

Table III. Task times for pre and post evaluation.

WMFT / Time(seconds)	Sub 1		Sub 2		Sub3		Sub 4		Sub 5	
Task	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Lift can	20.7	12.81	45.97	14.32	4.34	3.78	45.59	12.06	3.00	2.08
Lift pencil	5.01	4.62	3.97	3.71	3.37	5.03	4.57	4.91	5.53	5.97
Lift paper clip	5.45	4.09	19.87	6.5	3.1	11.25	120	120	2.75	2.53
Stack checkers	8.57	17.06	11.28	120	10.57	34.71	120	13.47	7.07	8.77
Flip cards	20.77	24.65	46.15	49.06	21.78	14.04	120	120	17.85	22.29
Turn key in lock	27.07	23.4	21.56	120	22.18	17.53	120	120	75.10	39.07

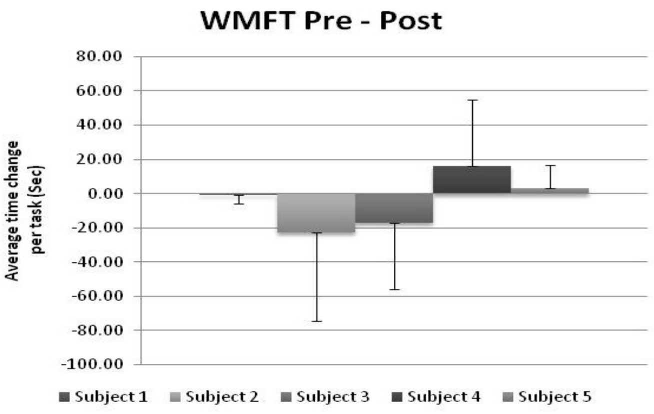

Figure 3. Hand Function results from 6 tasks of the WMTF showing the differenc in time between pre and post evaluations. Error bars indicate one *SD*. Positive values indicate improvement.

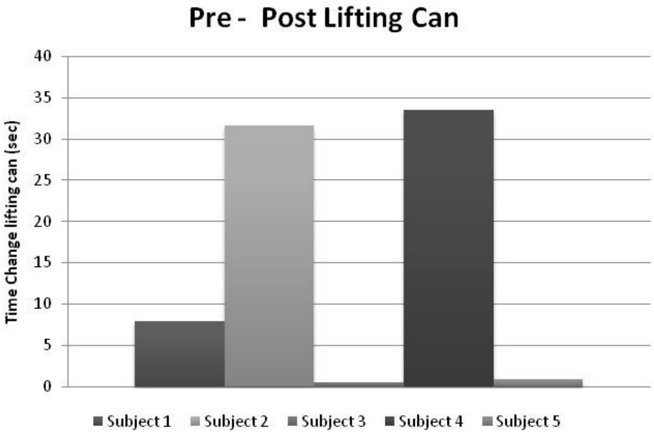

Figure 4. Lifting Can task results from the Wolf Motor Function Test showing time between pre and post evaluations.

Interestingly, the recorded EMG signals from the FDS and EDC muscles exhibited some important changes over the course of the training. For example, ***Figure*** *5* shows the difference in EDC versus FDS EMG magnitude over 4 cycles of hand opening and closing for one subject. The data obtained show a considerable increase in the difference in agonist-antagonist activation levels (i.e., EDC-FDS) during hand opening after the 6 weeks of training. The increase seemed to result largely from an increase in EDC activation (see ***Figure 6***). The EDC activity during hand opening for this subject increased by an average of 177 mV for session 18 as compared to session 1. This change corresponds to 15% of the full potential range of the EMG signal (1200 mV).

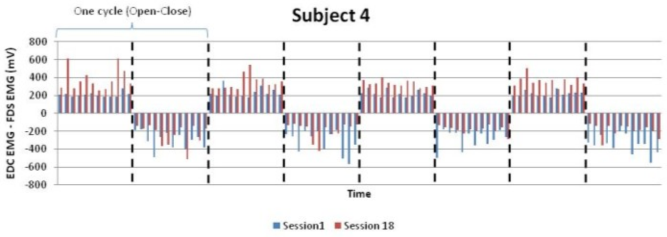

Figure 5. EMG activity of subject 4, showing the recorded EMG while the subject was performing four cycles of hand opening and closing during the last (red) and the first (blue) training sessions. The dashed lines delimit transitions from hand opening to hand closing. The difference between EDC and FDS activity is shown.

Two other subjects showed signs of increased EDC activity after completing the training paradigm as well (Fig. 6). While FDS EMG signals also increased for these subjects, the gain in EDC EMG activity was greater, on average.

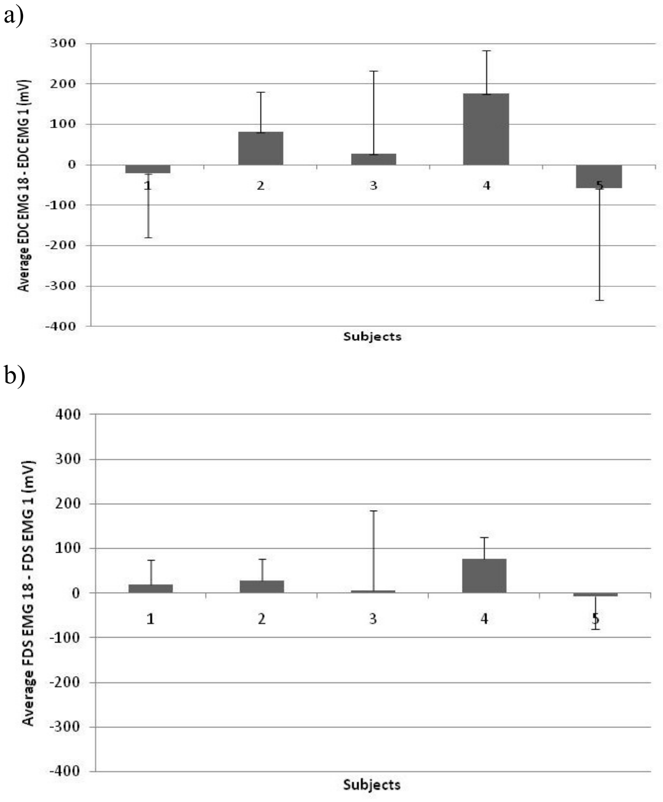

Figure 6. a) Average of the EDC EMG activity during hand opening during the last session (18) minus that of the first session (1), b) Average of the FDS EMG activity during hand opening during the last session (18) minus that of the first session (1). Error bars indicate one *SD* of the differences between the sessions.

IV. DISCUSSIONS

Five stroke survivors with significant chronic hand impairment participated in this pilot study examining the use of an EMG-driven orthosis to facilitate hand rehabilitation following stroke. All 5 subjects were able to use EMG signals to control opening and closing of the J-Glove. User feedback about the device was generally positive and all subjects completed the full 18 training sessions for the study.

For the WMFT component most like the grasp-and-release training performed by the subjects, namely, the Lift Can task, improvement was seen across all 5 subjects. While the absolute time reduction for this test was small (less than one second) for two of the subjects, that was because their completion time before beginning the training sessions was quite good (less than 5 seconds). The percentage by which time for this component was reduced for each subject was: 38%, 69%, 13%, 73%, and 31%. Additionally, three subjects showed improvement of 3 points or greater on the ARAT.

Consistent improvement was not seen in the other components of the WMFT that were used in the evaluation. Some of these other tasks were either not as difficult for the subjects even before training, such as Lift Pencil, so that little improvement was possible, or required arm movements that remained difficult even after training, (e.g., Flip Cards and Turn Key in Lock). The training was not directly intended to improve arm functions, although that might have been achieved by the training. It is also important to mention that objects such pencil or paper clip require different type of grip than the trained with the current version of the J-Glove.

Intriguingly, some of the subjects showed signs of changes in activation patterns after the training paradigm. For example, subject 4 exhibited an increase in the amount of EDC activity versus FDS activity during hand opening in the final training session as compared to the first training session (Fig. 5). This difference resulted largely from an increase in the desired EDC activity (Fig. 6). Intriguingly, the two subjects who exhibited greatest improvements in the WMFT task of lifting the can also showed the greatest increases in EDC activation over the training. It should be noted, however, that these absolute EMG values can be affected by factors such as electrode placement and skin condition.

While EMG-triggered electrical stimulation has been tried for hand therapy following stroke [14][15], the use of EMG-controlled robots to assist therapy remains rare. The use of EMG signals to control hand exoskeletons has been described [16][17], but results from training studies have yet to be reported. Our preliminary results suggest that this type of therapy may hold promise for initiating positive change following stroke.

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