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Myoelectric Computer Interfaces to Reduce Co-contraction After Stroke*

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Abstract— **A significant factor in impaired motor function caused by stroke is the inability to activate muscles independently. While the pathophysiology behind this co-contraction, sometimes called abnormal muscle synergy, is not clear, reducing the co-contraction could improve overall arm function. This pilot study describes the use of a myoelectric-computer interface (MCI) to retrain arm muscle activation and reduce co-contraction. We found that both healthy subjects and stroke survivors with hemiparesis learned to reduce co-contraction with MCI training. Three out of five stroke survivors experienced some improvement in arm function as well. These results suggest that MCIs could provide a novel, relatively inexpensive paradigm for stroke rehabilitation.**

I. INTRODUCTION

Each year, more than 350,000 people in the U.S. suffer hemiparesis from a stroke [1], and over half of stroke survivors have impaired hand or arm movement. In addition to weakness, spasticity and co-contraction cause major impairments [2, 3]. In contrast to spasticity, which is increased tone during passive limb movement, co-contraction (also called “abnormal muscle synergies,” consists of increased tone during active (or attempted) movement by the patient. Stroke survivors often experience co-contraction of anterior deltoid with biceps, and posterior deltoid with triceps. This constrains their movement to stereotypical patterns [4]. By reducing co-contraction and increasing the ability to independently activate muscles, it may be possible to improve function by restoring more normal patterns.

Abnormal muscle synergies can also be defined by abnormal coupling between joint torques. Ellis et al. recently demonstrated that abnormal joint torque couplings in stroke survivors could be modified by training the subjects to isolate individual joint torques [5]. The increase in strength and reduction in abnormal torque couplings observed after the progressive resistance training regimen was hypothesized to be due to neural adaptations that retrained the muscle co-contraction patterns.

This study attempts to reduce co-contraction more directly by using a myoelectric computer interface (MCI). In an MCI, surface EMG signals are mapped to cursor movement on a monitor. Radhakrishnan et al. [6] found that healthy subjects learned to control cursor movement to targets using muscle mappings in both intuitive (i.e. direction of cursor movement similar to natural muscle movement directions) and non-intuitive arrangements by forming new combinations of muscle synergies. Thus, MCIs may provide new method to retrain muscle activation patterns.

We first tested the MCI on healthy subjects to determine whether they could learn to decouple two normally co-contracting muscles (biceps and brachioradialis). Then we tested the extent to which stroke survivors could learn to decouple two abnormally co-contracting muscles (biceps and anterior deltoid). Our results suggest that stroke survivors can use a MCI to reduce abnormal co-contraction and improve upper limb function.

II. METHODS

A. Subjects

Five right-handed adult subjects (4 men, 1 woman) free from neurological and musculoskeletal disorders participated in this study. Five subjects (1 man, 4 women), ages 50-58, whose stroke occurred more than one year (range 2 to 25 years) prior to enrollment, also participated in this study. All subjects gave informed consent. This study was approved by the Northwestern University Institutional Review Board. Inclusion criteria were moderate to severe impairment of the affected arm (equivalent to a score of 12-40 on the upper-extremity portion of the Fugl-Meyer Motor Assessment) with chronic arm weakness and substantial co-contraction of the biceps and anterior deltoid muscles [7]. Exclusion criteria were significant acute or chronic pain in the upper limbs or spine, greater than minimal sensory loss in the affected upper arm, moderate to severe vision loss, or cognitive difficulty causing inability to understand or remember task-related instructions. All subjects that participated had hemiparesis including the right arm (Fugl-Meyer UE score 19 ± 3, mean ± SD).

B. Apparatus and Behavioral Task

Subjects were seated comfortably in a chair with their right arm resting on an attached armrest. Healthy subjects' arms were held prone and immobilized with cushioned restraints located at the hand, wrist and upper forearm. Impaired subjects' arms were held in a neutral (semi-pronated) position. A computer screen in the front of the subjects displayed a cursor (yellow circle) and square target of comparable size.

Subjects performed isometric contractions of multiple muscles to move the cursor to a randomly-selected target in a center-out task (Fig 1A) [5]. Activation of each muscle was mapped to one of four directions within the 2-D cursor space (described further in section D). The center target (CT) corresponded to zero net muscle activation. After the cursor was held in the CT for 500 ms, a red outer target (OT)

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located at a distance of 15 cm from the CT appeared and the CT disappeared, signaling the subject to initiate movement of the cursor by contracting one or more muscles. When the cursor reached the outer target it changed color to green. Subjects held the cursor within the OT for 500 ms to achieve a successful trial.

C. Myoelectric Control Signal

Cursor position was derived online from recorded EMG activity of multiple arm muscles. Surface EMG recordings were amplified with a gain of 1000 (Delsys Bagnoli EMG System), digitally sampled at 1 kHz (National Instruments USP-6229) and continuously collected in real-time using a customized program in BCI2000 [8]. The control signals in each direction were derived from EMGs by low-pass filtering at 500 Hz, rectifying, high-pass filtering at 20 Hz, and then convolving with a 400-ms rectangular window.

At the beginning of the experiment, subjects were informed of the specific directions corresponding to activation of each recorded muscle. At the start of each session (day), subjects were instructed to produce two maximum voluntary contractions (MVCs) of each muscle. The control signals were scaled by applying a classifier gain that allowed cursor movement to the edge of the workspace at a comfortable level of contraction (15-30% MVC). The control signals were mapped to uniformly-spaced directions of action (DoA). The vector sum of the control signals determined the 2-D cursor position (Fig. 1B).

D. Experimental Paradigm

Subjects performed one of two tasks, using either 2 or 8 outer targets. In the 8-target task, the two co-contracting muscles (biceps and brachioradialis for healthy subjects, anterior deltoid and biceps for stroke survivors) were mapped in opposite horizontal directions (Fig. 1B). In healthy subjects, an independent muscle (triceps) was added in the direction of brachioradialis. Two independent muscles (flexor and extensor digitorum for healthy subjects, triceps and either posterior deltoid or flexor digitorum in stroke subjects) were mapped in opposite vertical directions. In the 2-target task, the co-contracting muscles were mapped to orthogonal directions and only these signals were used in the summed control signal.

Due to a nonzero baseline level of involuntary, tonic muscle activity (mainly in biceps and flexor digitorum) in the affected muscles of some of the impaired subjects, the cursor was sometimes unable to reach the center target when the subjects tried to relax the muscles. Thus the resting activity of each muscle was averaged within a 250 ms window 1 s after the completion of a trial and subtracted from the corresponding control signals.

Healthy subjects participated in three sessions separated up to one week (days 0, 1, and 6). In each session, they performed ten minutes of the 8-target task (pre-training), followed by 20 minutes of the 2-target task (training), then ten minutes of the 8-target task (post-training). Stroke subjects participated in 18 sessions over 6 weeks (three sessions per week). In each session, they performed 10 minutes of the 8-target task, 30 minutes of the 2-target training task and another ten minutes of the 8-target task.

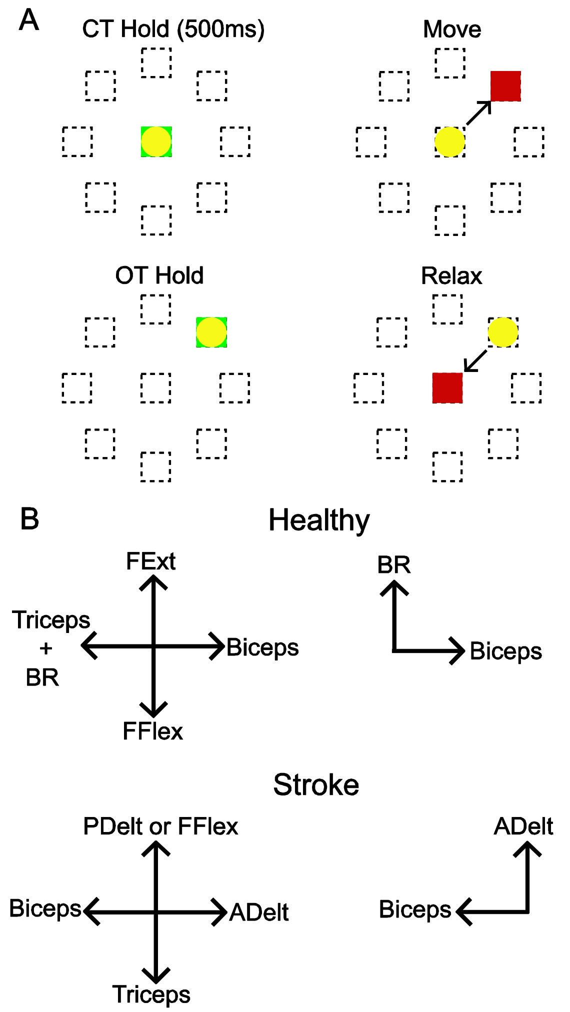

Figure 1. Schematic of the myoelectric-controlled interface (MCI) task and muscle mapping directions. (A) Subjects attempted to move the yellow cursor to one of either 2 or 8 (shown) red OT located radially from the CT using control signals derived from EMG activity. They were required to hold the cursor within the OT for 500 ms. Relaxing all muscles allowed the cursor to move back to the CT. (B) Arrangement of muscle direction of actions in both the 8-target task (left) and 2-target task (right) for both healthy and stroke subject groups. BR-brachioradialis, FFlex-Flexor digitorum, FExt-Extensor digitorum, ADelt-anterior deltoid, PDelt-posterior deltoid

E. Data Analysis

We assessed the degree of co-contraction between muscles by computing the Pearson correlation coefficient between the smoothed EMG of the muscles. We computed the correlation coefficient between the EMGs during the period from the appearance of OT to the end of the OT hold on consecutive trials that were concatenated.

We compared the correlation coefficients between the two normally co-contracting muscles (biceps and brachioradialis) in healthy subjects and the two abnormally co-contracting muscles (biceps and anterior deltoid) in impaired subjects across sessions to assess learning and across tasks to assess whether the behavior generalized.

III. RESULTS

A. Healthy: Decoupling normally co-contracting muscles

We found that healthy subjects learned to decouple two normally co-contracting muscles readily. The subjects adapted to the mapping within a session, and this adaptation persisted between sessions for at least one week, as seen in Fig. 2. In the training (2-target) task, there was a decrease in mean correlation of 0.26 ± 0.13 (mean ± SE) between the biceps and brachioradialis EMG from early training (first 2.5 minutes) in session one to late training (last 2.5 minutes) in session three, although this difference was not statistically significant (p = 0.12, paired t-test) There was a significant reduction in mean correlation from the pre-training phase of session one to the post-training phase of session three (0.29 ± 0.078, p = 0.021).

B. Stroke: Decoupling abnormally co-contracting muscles

Stroke survivors learned to dissociate the two muscles during the training task. Fig. 3 shows clear evidence of this learning across sessions. There was a significant decrease in mean correlations from early training of the first session to late training of the last session (0.45 ± 0.079, p = 0.0046). The correlations during pre- and post-training decreased only slightly over sessions (0.19, p = 0.29), suggesting that subjects had some difficulty generalizing the trained behavior to the 8-target task (Fig 3).

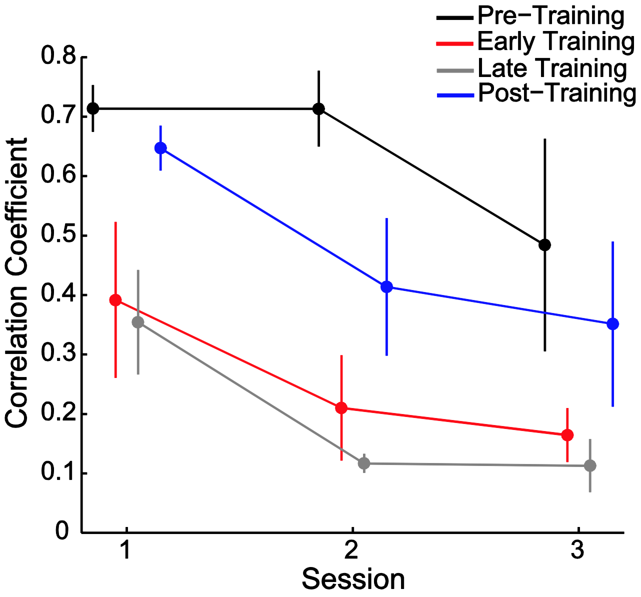

Figure 2: Mean correlation coefficients between biceps and brachioradialis EMG during the 2-target and 8-target task on three days separated up to one week. Vertical bars represent standard error. There was a significant decrease in correlation for both task conditions, indicating that subjects learned to decouple the normally co-contracting muscles.

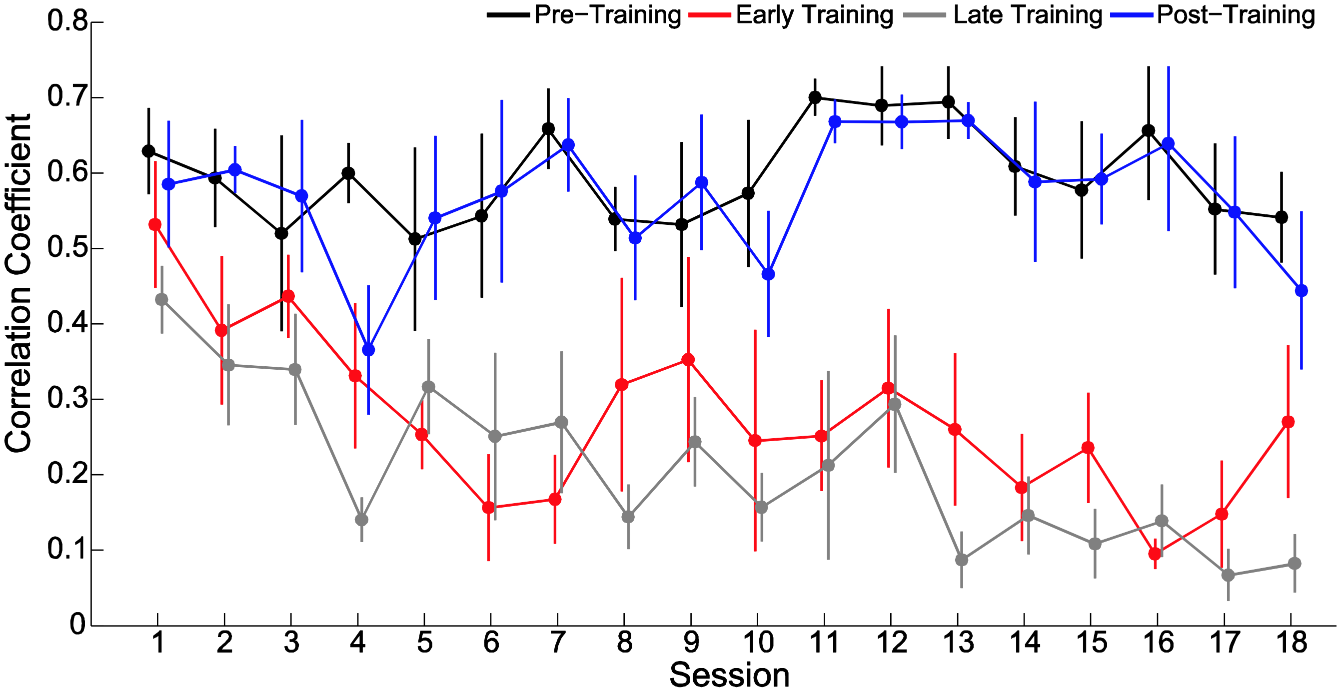

Figure 3: Mean correlation coefficients between biceps and anterior deltoids EMG during the 8-target task before and after training and during the first and last ten minutes (early and late training, respectively) of the 2-target task. Correlations significantly decreased during the 2-target task, indicating that subjects learned to decouple muscles with more training; however, they were unable to generalize this to the 8-target task.

IV. DISCUSSION

This study demonstrated that the MCI was an effective tool in enabling (1) healthy subjects to learn to decouple two normally co-contracting muscles and (2) stroke subjects to learn to decouple two abnormally co-contracting muscles. These results provide preliminary evidence suggesting that an MCI can be used to retrain directly muscle activation patterns and consequently improve overall arm function in the affected arm of stroke subjects.

Four stroke subjects reported subjective improvement of arm or hand function in activities of daily living during the study. Another subject reported improved strength and dexterity in hand flexion. Moreover, three subjects improved Fugl-Meyer scores by 3 points each at the end of the study, while the other two did not show a difference. The reduction in co-contraction may be attributable to the neural adaptations that reorganize the motor cortex and spinal cord and help regenerate new muscle synergies over long training periods [4, 9, 10].

An MCI provides a method to retrain directly muscle activation patterns while providing specific and intuitive feedback to the subject. It also allows flexibility in designing learning paradigms, since muscle activations can easily be remapped to different cursor directions and amplitudes. This will allow the system to be customized to each patient and target the specific muscles that show abnormal muscle activation patterns. While subjects all said they enjoyed the task, some did express a desire to make the task more interesting or varied. The MCI could be expanded into virtual environments that might increase patients' motivation while maintaining the benefits of physical intervention towards functional recovery.

The flexibility of the MCI also makes it possible to easily switch between various modes of muscle activation. In this study, subjects performed isometric contractions allowing us to target directly the abnormal co-contraction. While the isometric training showed a positive effect, most daily living activities require isokinetic contractions, and therefore it is possible that MCI training using free movements may translate to greater functional gains than isometric training.

It is unclear whether subjects were able to generalize the trained muscle synergies between the two tasks. The 8-target task was substantially more complex than the 2-target task since movement in the diagonal directions was required (which required combinations of two muscle activations) and each control signal was opposed directly by another. Subjects often compensated by increasing muscle activity in all muscles, which would have increased the level of co-contraction. The ability to generalize might have suggested a greater potential for translating to improved function; however, both the subjective reports and improved Fugl-Meyer scores suggest that the training did extend to activities of daily living.

The optimal amount of physical intervention that is needed to gain significant changes in functional outcome is an outstanding question, both in this and more conventional rehabilitation paradigms. Optimizing dosage of the MCI might further reduce co-contraction and improve overall arm function. Subjects were not overly fatigued by the task, and all expressed interest in increasing the training frequency or duration. Since the only requirements are surface EMG recording and relatively simple software, the system could easily be implemented in the community setting, and potentially even be used at patients' homes in the future allowing them to train more frequently. These results show promise, and we plan to investigate some of these issues in future studies.

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