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Coactivations of Elbow and Shoulder Muscles in Hemiplegic Persons with Chronic Stroke during Robot-Assisted Training

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***Abstract* – The motor recovery procedure of chronic stroke during robot-assisted training has not been well studied previously. In this work, we analyzed the variations in the coactivating patterns of elbow and shoulder muscles (biceps, triceps lateral, anterior deltoid, and posterior deltoid) in hemiplegic persons with chronic stroke (n=4) during a 20-session's interactive robot-assisted treatment. Significant decreases in muscle cocontractions (P<0.05) for all muscle pairs started from the 8th session of the training. Improvements were also observed in motor scores of Fugl-Meyer and Modified Ashworth Scale after the treatment. The results suggested an increased dexterity and selective control on individual muscles for both elbow and shoulder joints in a designed task after the robot-assisted training.**

I. Introduction

STROKE is a leading cause of permanent disability in adults, and hemiparesis is common in persons after stroke. Altered neural functions can be observed in the contralesional neuromuscular pathways in stroke survivors with unilateral brain injury, causing the consecutive neuromuscular changes, such as decreased motor unit firing rates, stiffened and shortened muscle fibers, muscle fiber type alterations, etc [1-3]. Those changes are often companied with clinical neuromuscular symptoms at the paretic side of stroke survivors, for example, weakness, spasticity, contracture and loss of selective control of muscle coactivations. Rehabilitation therapies are helpful to reduce motor impairments and to improve the functional use of the affected limb in persons after stroke. One of the factors for the success of a rehabilitation treatment is to understand the variation of the impaired neuromuscular system during the recovery procedure, based on which adaptive treatment can be applied [4]. Robot-assisted training is a relatively new approach for poststroke rehabilitation [5-8]. It has been reported that rehabilitation robots, especially with an interactive control strategy (rather than the devices only conducting passive motions), has been proven to effectively bring further recovery of poststroke motor function, even in the chronic stage after stroke [7]. In most of these studies, only pre- and post-assessments with some common clinical scales (e.g. Fugl-Meyer Assessment, FMA and Modified Ashworth Scale, MAS, etc.) on the motor functions were used for the assessment of the recovery due to the treatment [5-8]. However, seldom works have been done on monitoring and evaluating the recovery procedure during robot-assisted rehabilitation programs. Muscle coactivation patterns, reflecting the nervous control on the synergy of muscle groups, are highly related to the motor functions, such as stability, dexterity, and accuracy [9]. Excessive and abnormal muscular coactivations, associated with symptoms of stiffness, contracture, motion impairments, etc, are often observed in the affected limbs of persons after stroke [10]. In this work, the progressive changes in coactivations among elbow and shoulder muscles in hemiplegic persons with chronic stroke were studied by surface electromyographic (EMG) signals during a robot-assisted training, with the purpose of providing a better understanding on the motor recovery mechanism.

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II. Methodology

After obtaining approval from the Human Subjects Ethics Subcommittee of the Hong Kong Polytechnic University, we recruited 4 poststroke hemiplegic subjects for the study. All of the subjects were in the chronic stage (at least 6 months after the onset of stroke, male, age=48.8±8.5). Before the training, the FMA and MAS scores of the affected upper limb of the subjects were assessed by a therapist. Then, all subjects received an elbow training program, consisting of 20 sessions (5 sessions/week) at their affected limbs. After the training, the FMA and MSA scores were assessed by the same therapist again in the next day.

During a training session, the subject was comfortably seated, and the affected upper limb was placed horizontally on a motor-sensor system (The motor: Dynaserv, Yokogawa, Japan; and the torque sensor: AKC-205A, accuracy 0.03Nm, China) with the elbow joint positioned at the origin, as shown in Fig 1. The forearm of the affected side was fixed on a manipulandum, which could rotate with the motor. EMG signals (Noraxon electrodes, USA) were amplified (INA126, Texas Instruments, USA), collected, and stored in a computer from the muscles of biceps brachii (BIC), triceps brachii

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(lateral head, TRI), anterior deltoid (ADel), posterior deltoid (PDel). The sampling frequency for EMG signals was 1000 Hz (NI 6036E, USA). Before the training session, the EMG activities during the maximum isometric voluntary contraction (IMVC) of both elbow flexion and extension at 90^o of the elbow angle were recorded. The subject was required to conduct the voluntary elbow flexion and extension in the elbow range from 0^o to 90^o (0^o represented the full extension) by tracking a target cursor moving with angular velocity of 10^o/sec for both flexion and extension on the screen. During the tracking, supported torques were provided by the motor, which were proportional to the EMG amplitudes of biceps and triceps muscles as introduced in Song's study [11]. In a training session, there were 18 sections, and each section had 5 cycles of elbow extension-flexion. Resistances with 10% and 20% of the torques during the IMVC were generated by the motor and alternatively added to sections in one session.

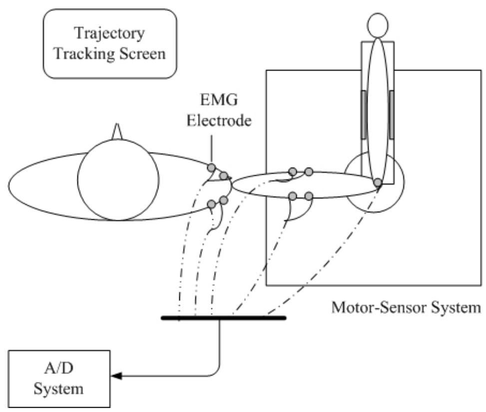

Fig 1. The diagram of the training system.

The EMG signals were processed offline. Linear envelopes of the raw EMG data were created by bias removal, full-wave rectification, low-pass filtering (3 Hz Cut-off frequency) and normalized to the largest value of activation observed in each muscle during either a training session or the IMVC before the training. The coactivations among muscle pairs during the training were studied by the cocontraction index (CI) as introduced in Frost's study [12]. As representative EMG trial segments from BIC and TRI (Fig 2), the CI of the two muscle was 2.1%, by calculating the area of the EMG overlap and then dividing by the number of data points.

The CIs of different muscle pairs were calculated for each section of every other session. Statistical analysis on the CI variations during the training for different muscle pairs were analyzed by one-way analyses of variance (ANOVA, repeated measures) with Bonferroni post hoc test. The statistical significant level was 0.05 in this work.

III. Results

The pre- and post-training motor functional scores evaluated by MAS and FMA were listed in Table 1. The scores of MAS decreased for most of the subjects, and increase in FMA was found for all subjects.

Fig 3 shows the variations of the CI for different pairs of muscles during the training. It was found in all muscle pairs that CI values varied not significantly within the first 8 sessions, except an increase in the CI values of BIC and PDel (1-way-ANOVA, $P<0.05$, with post hoc tests, $P<0.05$). All CIs demonstrated a common decreasing tendency after the 8^{th} session (1-way-ANOVA, $P<0.0001$, with post hoc tests, $P<0.05$). The maximum mean value of CIs was found at the 8^{th} session for all muscle pairs.

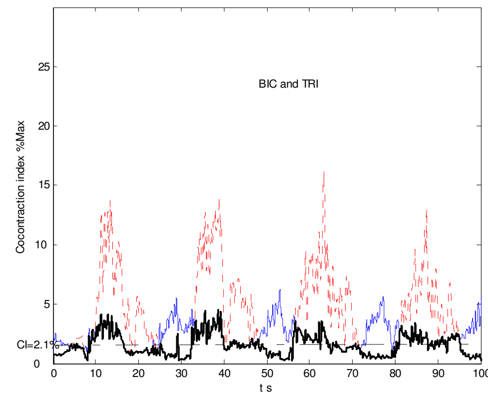

Fig 2. Representative EMG trial segments from BIC (thin solid line), TRI (dotted line), and their overlap (thick solid line).

IV. Discussion

For chronic stroke subjects, it was found that interactive robotic treatment was effective in motor functional improvement [7]. In this work, motor functional scores of MAS and FMA of all hemiplegic subjects were also improved after 20-session's robot training. The reduced MAS scores suggested an increase in flexibility of the elbow joint, and reduced excessive muscle activation attributed to spasticity [7] after the training. The improved FMA implied the enhanced voluntary control ability in upper limb functions in unconstrained common movements.

The decreased CIs in all muscle pairs in Fig 3 suggested the improved motor control on individual muscles related to both elbow and shoulder joints for the experimental task (the tracking). However, this improvement started from the middle (the 8^{th} session) of the whole training, and there was no clear stable states reached by the decreasing CIs for most of muscle pairs at the end of the training. This suggested that 20 sessions were necessary for the robot-assisted elbow treatment to improve motor functions of chronic stroke. The training first reduced the cocontraction between the antagonist muscle pairs related to elbow flexion and extension, i.e. BIC and TRI. Excessive muscle cocontractions in persons after stroke not only existed at single joint, but also could be cross-jointed [13]. The robot-assisted training also brought down the cocontractions between the muscles related to the elbow and shoulder joints (BIC & ADel, BIC &PDel, TRI & ADel, and TRI & PDel). It was interesting to see that the training on the elbow could reduce the cocontraction between the shoulder antagonist muscles, i.e. the ADel and PDel. The reduced CIs for all muscle pairs could be caused by the decreased EMG activation levels of the related muscles and better selective activations of individual muscles when conducting the tracking, which indicated an increased dexterity in a designed task and a motor relearning process.

The results in this work could provide further quantitative understanding on the motor functional recovery of chronic stroke during interactive robot training.

Subject	Affected Limb	Pre-Training		Post-Training	
		MAS	FMA	MAS	FMA
1	R	2	20	1	23
2	L	1+	15	1	22
3	R	2	19	1	21
4	R	1+	18	1+	20

Table 1. The motor impairment of the subjects before and after the training, measured by the Modified Ashworth Scale (MAS) and Fugl-Meyer Assessment (FMA). The maximal score of FMA was 66, which included the tests for shoulder and elbow.

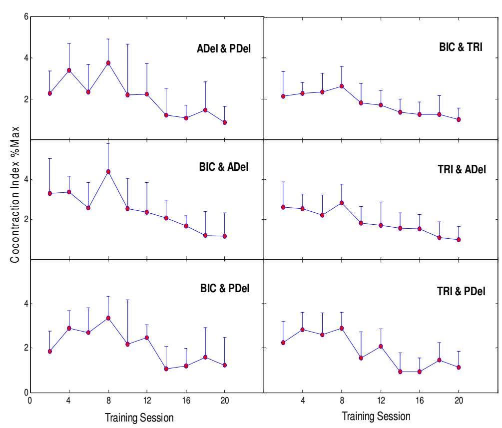

Fig 3. The variations of the CI for different pairs of muscles during the training.

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