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The Therapeutic Effects of Myoelectrically Controlled Robotic System for Persons after Stroke-A Pilot Study

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Abstract **–In this study, a myoelectrically controlled robotic system with one degree of freedom was developed to assist elbow training in the horizontal plane for patients after stroke. The system could provide assistive extension torque which was proportional to the amplitude of the subject's processed and normalized electromyograhpic (EMG) signal from triceps. The system also provided different resistive torques during movement, which were based on the maximum isometric voluntary extension (MIVE) and flexion (MIVF) torques. A study investigated its effect after 20-session of training for four weeks on the functional improvement of the affected arm in 3 subjects after stroke. Outcome measurements on the muscle strength at the elbow joint showed that there were increases in the MIVE and MIVF torques of the affected arms of all the subjects after the four-week rehabilitation training. The subjects could also reach a more extended position without the assistance of the robotic system than that before the four-week training.**

I. Introduction

STROKE is a primary cause of serious disabilities in Hong Kong. Approximately 25,000 strokes occur each year, causing 3,000 deaths and significant disability for many survivors [1]. Therefore, it is important to help such patients with disabilities to regain optimal physical functioning and allow them to take an active independent role in activity of daily life. Conventionally, motor relearning training can be conducted by therapists in hospital. In recent years, robotic systems have been developed to help subjects after stroke to restore the upper limb function for their well-controlled, repetitive, quantitative and adaptive characteristics [2]-[6]. Voluntary, focused physical training is important to promote the recovery of brain for patients after stroke [7], but the assistance from the current rehabilitation robotic systems is seldom related to the intention of the subject on the affected side. Myoelectric control is a useful way to relate the subject's intention to the control variable since EMG signals could reflect the activities of the muscles [8]. Many researchers have designed some exoskeleton systems, and used EMG signals as control source to assist the corresponding joint movements [9]-[10]. However, the therapeutic effect of using myoelectrically controlled robotic system for the rehabilitation training on subjects after stroke has not been investigated. In order to investigate its therapeutic effect, a myoelectrically controlled robotic system is developed together with a four-week training protocol to assist the rehabilitation training of elbow complex for subjects after stroke. Proportional myoelectric control was applied to improve the ability of elbow torque output during elbow extension in the horizontal plane.

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II. Methodology

The mechanical part of a robotic manipulator with one-degree of freedom (DOF) was designed and fabricated for assisting the movement of elbow flexion and extension on a horizontal plane, which was shown in Fig. 1.

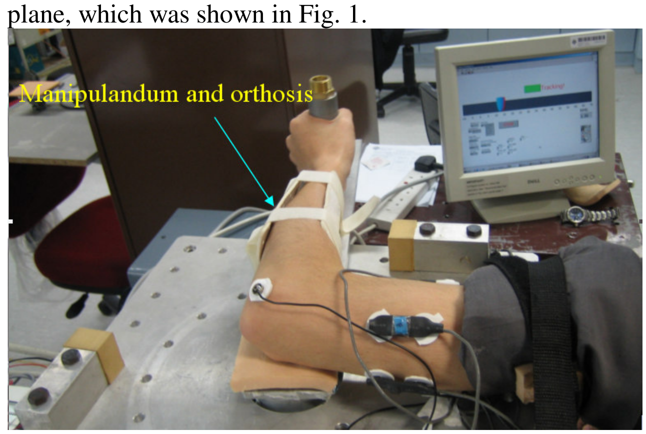

Fig. 1 Diagram of the robotic system

The inputs to the system were the EMG signals, the torque signal and the angle signal, which were captured through the data acquisition (DAQ) card (PCI6036E, National instrument, USA) These signals were inputted to the computer, and then the control signals would be generated and outputted to the servo driver to control the servo motor through the 16-bit analog output of the DAQ card based on the control strategy. Before sampling, the EMG signals were amplified with a gain f 1000 and were band-pass filtered in 10-400 Hz. The processed EMG signals were all sampled at 1000 Hz, and full-wave rectified and calculated with a moving window (100

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ms).The processed EMG signals w_j were then normalized to the range 0-1 for $NEMG_j$ as follows:

$$NEMG_j = \frac{w_j - w_r}{w_{mvc} - w_r} \quad (1)$$

where w_r was the amplitude of processed EMG signal at rest, and w_{mvc} was the maximal amplitude of the processed EMG signal during maximum voluntary contraction (MVC). The assistive torque T_{assist} was estimated based on the normalized EMG signals:

$$T_{assist} = G * T_{mvc} * NEMG_j \quad (2)$$

where G was the gain parameter between EMG and assistive torque, and T_{mvc} was the measured torque during the MVC. Then the resulted torque T_{result} from the motor was shown in the following equation:

$$T_{result} = T_{assist} - T_{resist} \quad (3)$$

where T_{resist} was a constant resistive torque applied to the motor based on the maximum voluntary contraction at the elbow joint, which was designed to develop muscle strength for subjects after stroke in the rehabilitation training.

During the experiment, the subjects were asked to sit beside the system. A strap was used to hold the affected upper arm to a supporter in the horizontal plane and the shoulder was in 90 deg abduction. The affected forearm was attached to the manipulandum, and the subject was asked to grasp the handle of the manipulandum. The orthosis and strap were used to attach the forearm to the manipulandum. A screen was placed in front of the subject to provide guidance, and all the subjects were instructed to complete the following tasks:

The maximum isometric voluntary extension (MIVE) and flexion (MIVF) torques were measured for the affected elbow flexors and extensors when the elbow was positioned at 90 deg in the horizontal plane, which were used to define the level of resistive torque generated by the motor for each subject. The EMG signals during MIVE and MIVF were also captured to normalize the EMG signals of the biceps and the triceps.

After the torque measurements, the subjects were asked to perform a repetitive arm tracking test which began with the elbow at 90 deg. In each trial, after a 3-sec delay from the beginning of the program, the indicator light in the middle of the screen turned green to instruct the subject to start following the target. First, the target would move from 90 deg to 0 deg at a constant speed of 10 deg/s, and the subject extended his/her affected elbow with the myoelectrically controlled system; then the target pointer would pause at 0 deg for 3 seconds; then the target pointer would come back from 0 deg to 90 deg at a constant speed of 10 deg/s to complete one cycle, and the subject flexed his/her affected elbow with the myoelectrically controlled system back to 90 deg. Five cycles were conducted in each trial, and it took 2 min to complete one trial. The LCD monitor in front of the subjects displayed both the target angle and the actual elbow joint angle with the two pointers. The subjects could correct the elbow movement to match the target pointer with this real-time visual feedback. If the subject could not extend his forearm to follow the target pointer, he would be suggested to stop at the largest extended position and wait for the target pointer to come back so that he could follow it again. During the elbow extension, the robotic system would generate an assistive torque which was proportional to the amplitude of the processed triceps EMG signal to assist elbow movement together with a constant resistive torque which was a percentage of the MIVE torque. During the elbow flexion, there was only a constant resistive torque which was a percentage of the MIVF torque and no assistive torque was applied. In each session, subject was trained with different combinations of the EMG-torque gain (50% and 100%) and the resistive load (0%, 10% and 20%). Moreover, each subject was also asked to perform an evaluation trial without any assistive and resistive torque from the robotic system. There was a one-minute resting period after each trial, and the total time for one session together with the evaluation trial was about 120 minutes.

III. Results

This study was reviewed and approved by the human ethical committee of the Hong Kong Polytechnic University. Three male subjects after chronic stroke were recruited in this four-week training program. Before the experiment, all the subjects were made to understand the experimental procedures and duration, and they signed the consent forms. Results showed that the design could enable subjects with weak triceps to extend their affected elbows to a more extended position with the assistance of the myoelectrically controlled robotic system (shown in Fig. 2). There was an obvious improvement in the extension range for all the subjects after the four-week rehabilitation training. the extension range of Subject A and subject C increased from 66.8 deg to 90 deg and from 62.5 to 90 deg, respectively, while the extension range of subject B also had an improvement from 51.3 deg to 82.7 deg. Fig. 3 plotted the elbow trajectories of the evaluation trial of subject C in different weeks during the voluntary elbow tracking. With the processing of the rehabilitation training, we could found a continuously increase in the active range of elbow extension in the evaluation trial. The root mean square error (RMSE) between the target angle and the actual elbow angle in the evaluation trial of 20 consecutive sessions were presented in Fig. 4. From this figure, the RMSE dropped with the process of the training sessions, which reflected the improvement of the elbow function during the rehabilitation training.

The torque signals measured by the robotic system were also used to evaluate the improvement in muscle strength during the rehabilitation training. The MIVE and MIVF torques were shown in Fig. 5. The myoelectrically controlled robotic system had a positive effect in developing muscle strength.

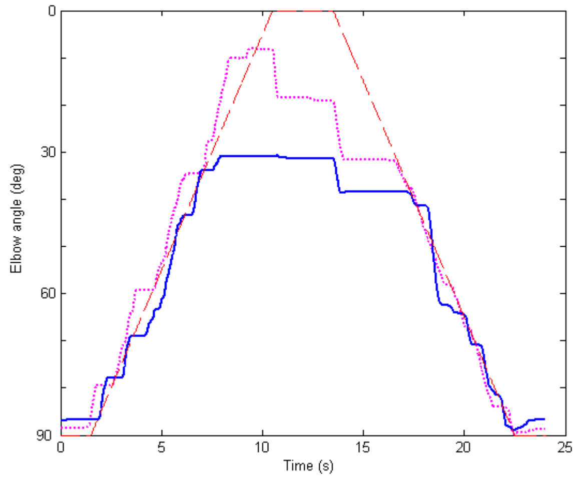

Fig. 2 The trajectories of subject C with (dotted line; gain=100%, load=0%) and without (solid line) the assistance from the robotic system during the voluntary elbow tracking at a velocity of 10 deg/s

IV. DISCUSSION

Some studies had suggested that the training at shortened muscle length was more effective in developing muscle strength at such muscle length [11, 12]. However, subjects after stroke often had difficulties in training the triceps at such position. It was hard or even impossible to reach such range due to contracture, muscle cocontraction or muscle weakness. The assistive function of the myoelectrically controlled robotic system could enable subjects after stroke to train at this range (shown in Fig.2), which might have a potential beneficial effect. On the other aspect, the assistance from the robotic system did not transform the active exercise into a passive manipulation due to myoelectric control. The sensorimotor integration theory suggests that the voluntary efferent output as well as the afferent input might promote brain recovery [13]. The result showed that the myoelectrically controlled robotic system might have a positive effect to improve the upper limb function for subjects after stroke. In order to further confirm its clinical efficiency, the system should be compared with other existing methods in a randomized controlled experiment at the next stage.

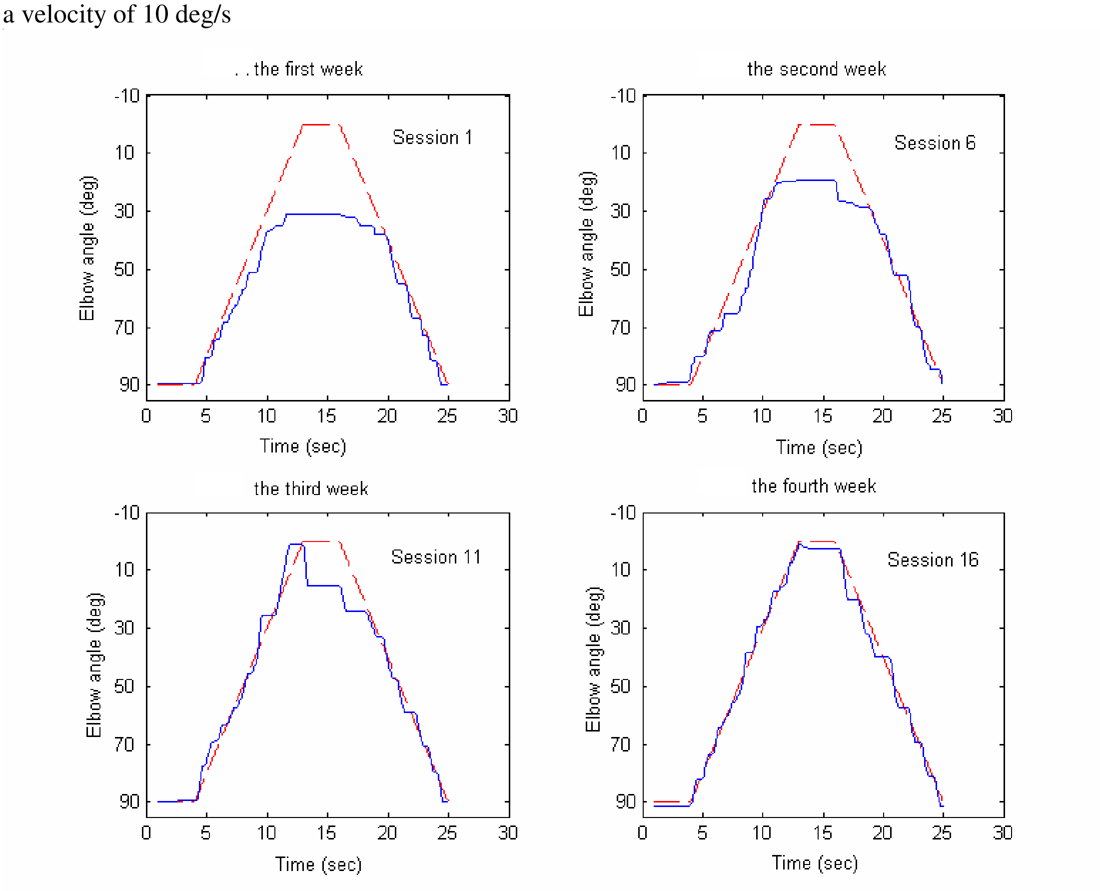

Fig. 3 The elbow trajectories (solid line) of the evaluation trial of subject C in different weeks during the voluntary elbow tracking at a velocity of 10 deg/s. The dashed line was the target trajectory.

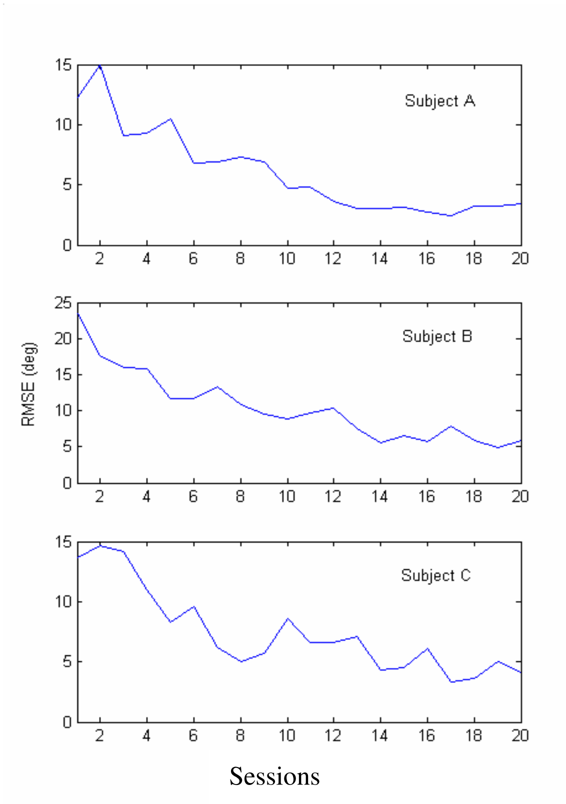

Fig. 4 The RMSE between the target trajectory and the actual elbow trajectory of the evaluation trial in the 20 consecutive sessions.

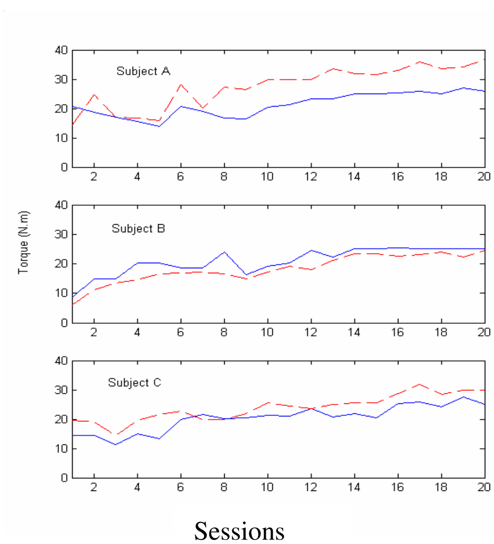

Fig. 5 The MIVE torque (dashed line) and MIVF torque (solid line) of three subjects in the 20 consecutive sessions.

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