A method for the evaluation of the elbow functional control in patients after stroke

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Abstract

The purpose of this study was to quantitatively compare the difference between unaffected arm and affected arm of subjects after stroke in voluntary elbow tracking movements. Six subjects were recruited to perform voluntary elbow flexion and extension by following sinusoidal trajectories at different angular velocities (10, 20, 30, 40, 50, and 60 deg/s) on the horizontal plane. From experiment results, there was an increase of root mean square error (RMSE) in both affected arm and unaffected arm with the increase of tracking velocity. The RMSEs of unaffected arm were 2.76 ± 0.76, 4.24 ± 1.30, 5.82 ± 2.19, 7.47 ± 3.02, 9.77 ± 4.51, 12.46 ± 5.33 ***deg respectively from 10 deg /s to 60 deg/s, which is much lower than those of the affected arm (The RMSEs of affected arm were*** 3.95 ± 0.68, 6.34 ± 1.51, 8.85 ± 2.3, 10.87 ± 3.16, 12.80 ± 3.85, 16.71 ± 5.92 ***deg respectively from 10 deg/s to 60 deg/s). The result showed the RMSE can be a useful performance index to evaluate the elbow control function of subjects after stroke during the tracking test.***

1. INTRODUCTION

Clinical scales, such as Ashworth score and Fugl-Meyer scale were often used to evaluate upper limb deficits from different aspects [1, 2]. However, most of these clinical scales are a semi-quantitative method, which may not be very sensitive to measure and detect small change during the rehabilitation.

In order to find the better treatment strategies and accurately evaluate the upper limb improvement of neruomusculoskeletal system during rehabilitation training, the upper limb function is better to be investigated comprehensively, extensively and quantitatively. Trajectory-tracking has been a useful tool to evaluate sensorimotor control function of upper limb which coupling both perception-action and motor execution [3, 4]. Furthermore, trajectory-tracking tasks provide a uniform scale for nervous system to follow and corrective by the feedback across different subjects.

The main objective of this study is to systematically identify the elbow control ability of subjects after stroke during voluntary elbow tracking tasks, RMSE between elbow angle and target angle is used as a performance index.

2. METHODS

2.1 Experiment procedures

A group of six subjects with stroke (four males and two females) were recruited in this study. The mean age of subjects was 48 ± 6.9 years with the range of 37 – 57 years. Before the test, all subjects were introduced with the experiment protocol and gave informed consents which followed the procedures established by The Hong Kong Polytechnic University. In the experiment, subjects were asked to sit beside the table with the manipulandum (Fig. 1). A strap was used to fix the upper arm to a supporter on the table. The height of the table was adjusted so that the arm was in horizontal plane with the same height of the shoulder. The shoulder was in 90° abduction and 45° flexion. The forearm was attached to a manipulandum and the axis of rotation was in line with the elbow joint. There was a computer screen in front of the subjects, which displayed both target and measured elbow joint angle. When the indicator light on the screen turned green, the trial started and the pointer slide moved with the defined speed in a sinusoidal trajectory from 30° to 90° for 36 seconds (elbow angle was defined as 0° when the elbow was in full extension). The subjects were instructed to start at 30° and try their best to follow the target. The measured elbow angle was displayed in another pointer slide to form the real time feedback.

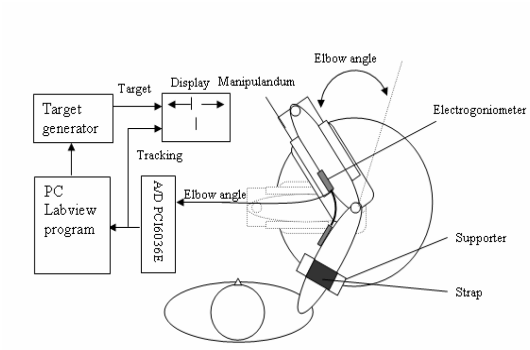

Fig. 1 Block diagram of experiment setup

Subjects were provided 18 trials structured in 3 sections, each section consisted of six trials with different angular velocities (10, 20 30, 40, 50, 60 deg/s) arranged in a random sequence. The subjects had a 30 s rest between each trial and 5 minutes rest between each section. All subjects performed the task with both affected and unaffected arms.

2.2 Data Analysis

Angular displacement of the elbow joint was recorded by a flexible electrogoniometer (Penny & Giles, UK), and the angular signals were filtered by a low-pass filter using a zero-phase 4th order Butterworth digital filter with cut-off frequency of 5 Hz. RMSE between actual elbow angle and target angle was shown in Eqn. 1:

$$\text{RMSE}=\left(\frac{\sum(\theta_0(i)-\theta(i))^2}{N}\right)^{1/2} \quad (1)$$

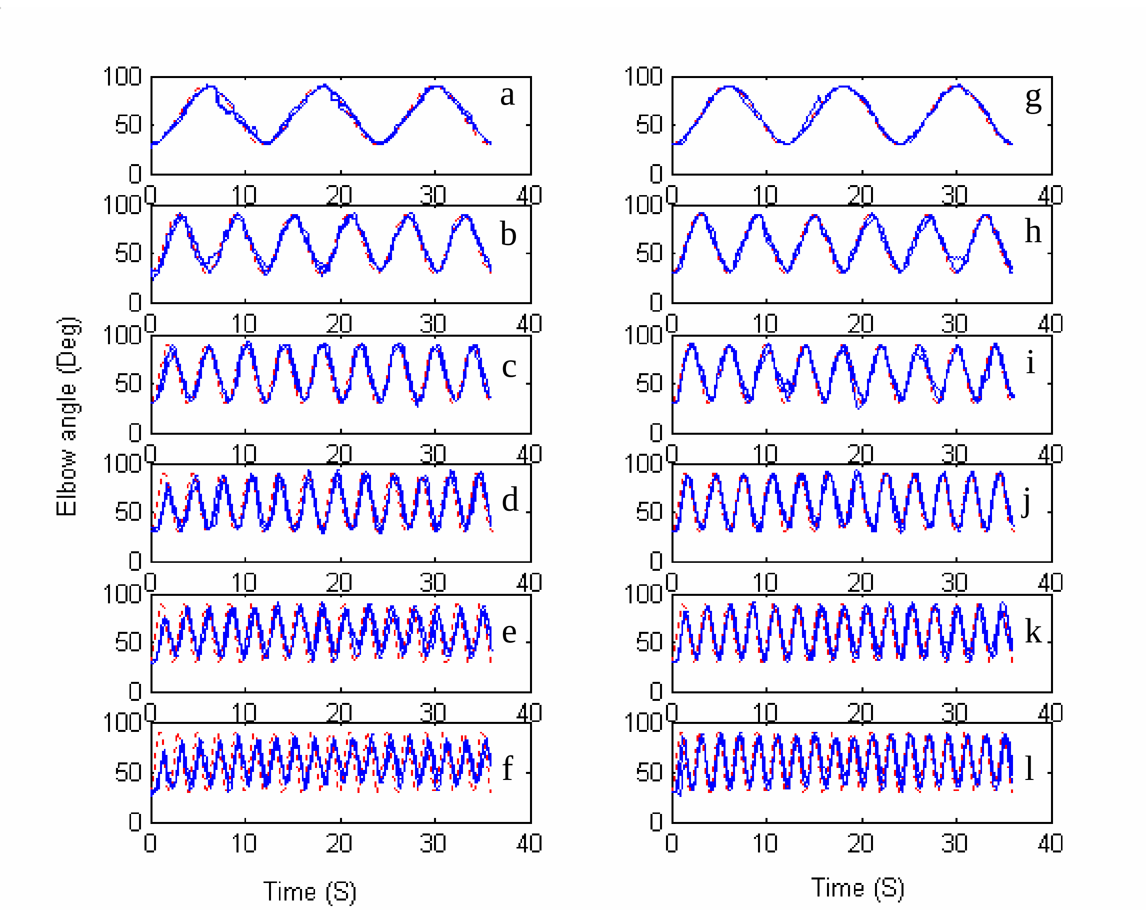

Fig. 2 Target (dotted line) and three measured elbow trajectories (solid lines) of affected arm (a, b, c, d, e, f), and unafected arm (g, h, i, j, k, l) of a stroke subject during voluntary elbow tracking at different velocities (a, g: 10 deg/s; b, h: 20 deg/s; c, i: 30 deg/s; d, j: 40 deg/s; e, k: 50 deg/s; f, l: 60 deg/s)

Where $\theta_0(i)$ was the target elbow angle at ith sampling instant and $\theta(i)$ was the actual elbow angle at ith sampling. N was the total number of samples. The RMSE was computed for each trial and averaged from the three trials with the same velocity.

A two-way (factor1: side, factor2: velocity) mixed design with repeated-measures analysis of variance (ANOVA) was used for affected side and unaffected side of subjects after stroke. Paired t-test was performed to test difference between two sides of subjects for each velocity. The significant level was set at 0.05.

3. RESULT

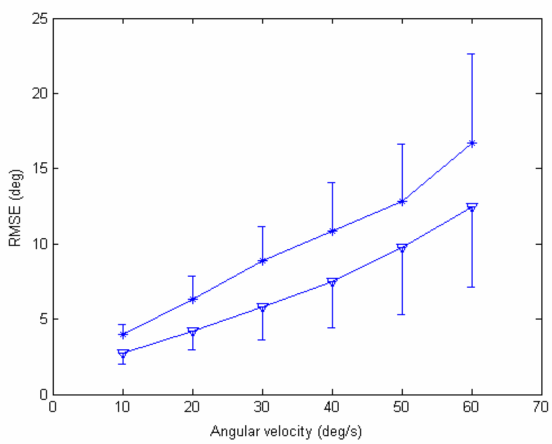

Fig. 3 Comparison between the RMSE of unaffected arm (∇) and the RMSE of affected (*) arm at six velocities (10, 20, 30, 40, 50, 60 deg/s) during elbow tracking movement. Vertical bars indicate standard deviation.

Fig. 2 showed the elbow angular trajectory of unaffected arm and affected arm from a subject at six velocities. The trajectory of the unaffected arm was smoother than that of affected arm. The RMSE values of unaffected arm were 2.76 ± 0.76, 4.24 ± 1.30, 5.82 ± 2.19, 7.47 ± 3.02, 9.77 ± 4.51, 12.46 ± 5.33 deg respectively from 10 deg /s to 60 deg /s, while the RMSE values of affected arm were 3.95 ± 0.68, 6.34 ± 1.51, 8.85 ± 2.3, 10.87 ± 3.16, 12.80 ± 3.85, 16.71 ± 5.92 deg respectively from 10 deg /s to 60 deg /s. Fig. 3 showed the comparison of RMSE between unaffected arm and affected arm with the effect of velocity. There was an increase in the root mean square error (RMSE) for both affected arm and unaffected arm with the increase of tracking velocity. The standard deviation also increased with tracking velocity. There was significant difference between RMSE of affected arm and unaffected arm with two way repeated measures ANOVA ($p<0.001$). There is a significant increase of RMSE of affected arm in compare to unaffected arm at all the velocities ($p<0.05$).

4. DISCUSSION AND CONCLUSIONS

Because of the damage in the motor cortex and immobilization after stroke, there are many factors that interfere with the sensorimotor control function of upper limb: muscle weakness [5], response delay [6] and abnormal muscle activation [7] which may affect the arm tracking result of affected arm. This study showed significant difference between affected arm and unaffected arm during arm tracking experiment at different velocities. This is an alternative method to evaluate elbow functional control of patients after stroke.

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Acknowledgments

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