上肢復健機器人評估中風病患不正常協同動作

Upper Extremity Rehabilitation Robot for Evaluating Abnormal Synergies of Stroke Patients

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摘要

在臨床上發現，物理治療師幫助中風病人做復健治療時，中風病人會有不正常協同動作的現象產生。本研究的目標是發展一套可客觀定量評估協同動作的系統。利用復健機器人記錄病患進行不同方向直線軌跡追蹤時運動學、動力學與肌電圖資訊，用來評估病患不正常協同動作的程度。實驗結果顯示所發展的客觀評估指標可量化出病患的不正常協同動作。

關鍵詞： 協同動作、肌電圖、中風、復健、機器人

INTRODUCTION

Conventionally, rehabilitation programs rely heavily on the experience and manual manipulation technique of the therapists. Since the number of patients is large and the treatment is time-consuming, it is a great advance if robots can assist in performing treatments. Recently there have been many researches working on how to use robots in assisting patients in rehabilitation [1, 2].

Brunnstorm showed that recovery from hemiplegia occurred in a stereotyped sequence of events [3]. At first, recovering patients could only move in abnormal synergies. For the upper extremity, these abnormal synergies were described as the flexor synergy (characterized by simultaneous shoulder abduction, elbow flexion and forearm supination) and the extensor synergy (characterized by simultaneous shoulder adduction, elbow extension and forearm pronation). Later, as recovery progressed, the abnormal synergies were broken down and voluntary functional movements appeared. In clinical evaluation scales (ex. Brunnstrom's stage and Fugl-Meyer scope), the level of synergy is estimated but it heavily depends on the judgment of therapists. Hence, the main goal of this work was to develop a system to objectively and quantitatively evaluate the abnormal synergies of stroke patients.

METHODS

In our previous study, a rehabilitation robot was developed for neuro-rehabilitation of the upper extremity [4]. The robot could assist in the shoulder-elbow and wrist movements (Fig 1a). The weight of the forearm was supported by the two-link passive mechanism. The robot was designed to perform two-dimensional movements in a planar workspace and was able to provide a 30% maximum voluntary contraction resistant force to the subjects. Straight-line tracking movements in four directions were designed in this research (Fig. 1b). During the tracking movements, the subject's forearm was fixed by the clamp. The robot could record forearm pronation/supination torque τ_f by a torque sensor and elbow flexion angle θ_e by a goniometer.

EMG signals were measured by eight surface electrodes (Delsys, Inc.) from the following muscles: pectoralis major (PEC), middle deltoid (DEL), biceps bachii (BIC), triceps bachii (TRIC), pronator teres(PT), supinator (SUP), flexor digitorum superficialis (FDS), extensor digitorum (ED). The signals were amplified with a gain of 1000 V/V and a band-passed of 20 Hz to 450 Hz and sampling frequency at 2.0K Hz/channel. Signals were processed by full-wave rectification and line envelope. The recorded EMG was first normalized with the EMG during isometric contraction and, then, smoothed by an adaptive filter (cutoff frequency 0.25~2.5Hz) [5].

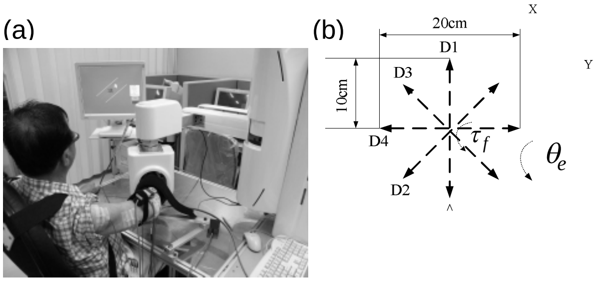

Fig. 1. (a) A photograph of a stroke patient with the rehabilitation robot (b) Four directions of straight-line tracking movements

Biomechanics assessment indices:

Pearson's correlation coefficient r_{fe} between τ_f and θ_e was adopted as an indicator of abnormal synergies. Another index, IADT (Integration of Absolute Deviation of Torque),

$$IADT = \int \left| |\tau_f| - |\bar{\tau}_f| \right| dt \,, \qquad (1)$$

where over bar denoted the mean value, was used to estimate the total variation of τ_f. Larger IADT indicated larger variation of forearm pronation/supination torque.

EMG assessment indices:

The principal component analysis (PCA) was adopted to describe the correlation between the upper-limb muscles. The relative principal components (PCs) were used to quantify the degree of variance in the data [6].

RESULTS AND DISCUSSION

Eight age-matched able-bodied subjects (6 males and 2 females, mean age 50.5 years, SD 8.1) and eight stroke patients (8 males, mean age 49.5 years, SD 9.8), were recruited.

Fig. 2 shows the Pearson's correlation coefficient r_{fe} of able-bodied group and stroke group during straight-line tracking movement in different directions. While the results of both limbs of the able-bodied subjects and the intact side of strokes were close to zero or positive, the results of the affected limbs of strokes were negative.

Fig. 3 shows that IADT of able-bodied subjects' dominant, non-dominant limbs and strokes' intact limbs were around 50 while those of stroke patients' affected limb were around 100. Therefore, indices r_{fe} and IADT could be employed to quantify the abnormal synergies in stroke patients' affected limbs.

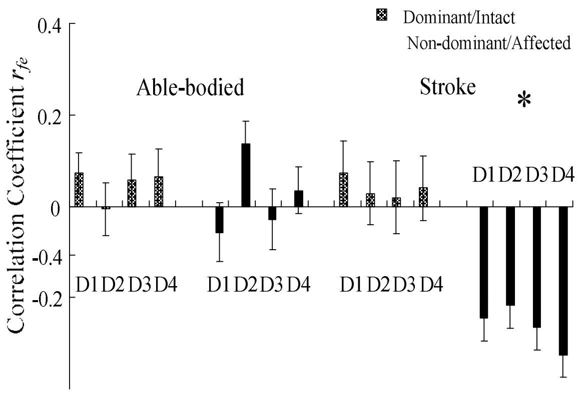

Fig. 2. Mean (with SEM) of Pearson's correlation coefficient r_{fe} of the able-bodied subjects and stroke patients.

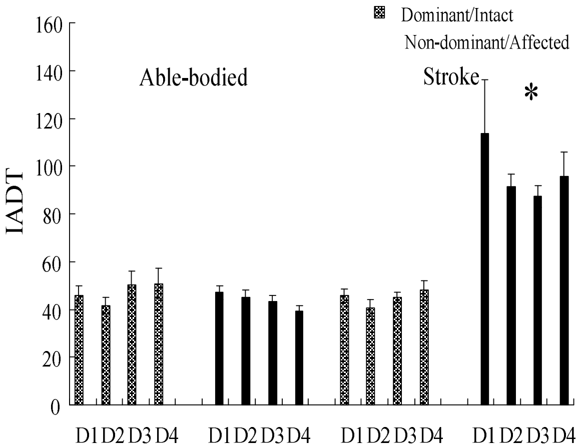

Fig. 3. Mean (with SEM) of IADT of the able-bodied subjects and stroke patients.

The largest principal component (PC1) of EMG signals from PEC, DEL, BIC and TRIC muscles were shown in Fig. 4. PC1 represented about 70% of total variance in both able-bodied subjects and stroke patient's EMG signals. It can be seen in Fig. 4 that, in all four directions, PC1 of PEC and BIC had the same "positive" sign. This might imply that there was a co-contraction of PEC and BIC during the tracking movements. Likewise, except in the case of stroke patient's affected limb, PC1 of DEL and TRIC showed similar "negative" sign for most of the tracking movements. As a result, for the able-bodied subjects' dominant and non-dominant limbs as well as stroke patients' intact limbs, contraction of PEC and BIC alternated with contraction of DEL and TRIC. In other words, two major groups of muscles were used in opposite phase during the straight-line tracking movements. On the contrary, for stroke patient's affected limb, PC1 of PEC, DEL, BIC and TRIC held the same "positive" sign in all four directions. It implied that the patients used all the muscles in the same phase, i.e., abnormal synergy, to complete the task. From above analysis, the largest principal component could be utilized to quantify the synergies of upper limb muscles for able-bodied subjects and stroke patients.

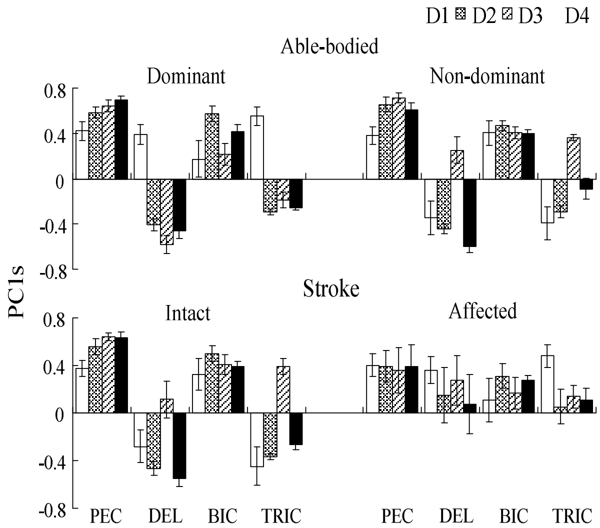

Fig. 4. Mean (with SEM) of PC1 of the able-bodied subjects and stroke patients.

CONCLUSIONS

Using the biomechanics and EMG assessment indices derived from the straight-line tracking movements in different directions, the abnormal synergies could be quantitatively evaluated.

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