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Study on sEMG-Based Exercise Therapy for Upper Limb of Severe Hemiplegic Patients *

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***Abstract*—sEMG, as a kind of bioelectrical signal reflecting muscle motion state, generally applies to motion recognition and human interface. Healthy subjects are selected in most studies, while for hemiplegic patients, especially patients with severe hemiplegia, high accuracy motion recognition is difficult to acquire due to the non-ideal sEMG signal from dysfunction muscles. Therefore, this paper presents an upper limb exercise therapy, based on 5 defined motions and 6 Muscle-Units, for patients with severe hemiplegia. Through the sampling and analysis of sEMG signals from 8 subjects, including 4 healthy and 4 hemiplegic patients, we draw a conclusion of the relevance between specific motions and Muscle-Units, which can be used as a reference for paralyzed arm training. According to this relevance, six Muscle-Units can be classified into two categories: major Muscle-Units and minor Muscle-Units. In order to improve the interest and positivity of patients, a PC based virtual interactive platform is established. The sEMG signal from major Muscle-Units is processed with a moving average algorithm, and the result is used as the control signal for training interaction.**

I. Introduction

With the aggravation of the aging society, the number of patients with hemiplegia which is a common sequelae caused by stroke is increasing. Upper limb dysfunction, one of the main symptoms of hemiplegia, is seriously affecting the quality of life. Therefore, the study on treatment and exercise therapy for upper extremity function is of premier importance [1].

As an electrical signal which can directly reflects the human muscle motion, sEMG is widely used in the research of treatment and rehabilitation for hemiplegic patients, besides, human-computer interaction technology based on virtual reality provides a new means of the exercise therapy for patients [2]. Multi-channel sEMG signal are involved in many previous researches, such as motion recognition based on multi-channel sEMG signal features and classifiers [3]-[5], human-computer interface applications by multiple sensor [6][7], etc. In most studies, the subjects are healthy people without physical injury. However, for hemiplegic patients, especially patients with severe hemiplegia, the practical situation is quite different.

According to Brunnstrom method [8], rehabilitation of helmiplegic patients can be classified into six stages: flaccid, spasm, synkinesis, merodialysis, isolated joint movement and normal stage. The patients with severe hemiplegia described in this paper mainly refer to Brunnstrom I to III, who are lack of upper limb function and unable to complete the separate motions of hand, wrist, and etc. Due to the effect of muscle spasm or synkinesis, the sEMG signal acquired from paralyzed arms of patients is much weaker, and different from the features of healthy muscle group, so it is difficult for motion recognition with high accuracy. However, the motion law by healthy arms can provide a reference for treatment and rehabilitation of the affected arms. The traditional treatments for patients with severe hemiplegia are massage, acupuncture, electrical stimulation, etc. In order to make the rehabilitation of patients more targeted, the multi-channel sEMG signal was applied to our study. The study consists of two parts: 1) collecting multi-channel sEMG signals from different muscle positions through several subjects and specific motions, and obtaining motion law of muscle groups with data analysis; 2) according to the motion law of muscle groups associated with specific motions, applying the processed sEMG signal to virtual interactive platform for providing guidance and quantitative indicators to the rehabilitation training process.

II. METHODOLOGY

A. Subjects and defined motion

In the experiment, multi-channel sEMG signal were collected from 8 subjects, 4 healthy volunteers aged from 23 to 26 and 4 patients aged from 50 to 55 with different stage of hemiplegia from Brunnstrom I to IV. The subjects were required to complete 5 kinds of forearm motions which are widely used in research and rehabilitation exercise, including wrist flexion (WF), wrist extension (WE), wrist ulnar deviation (WUD), wrist radial deviation (WRD) and clench fist (CF), as shown in Fig. 1. All subjects provided consent

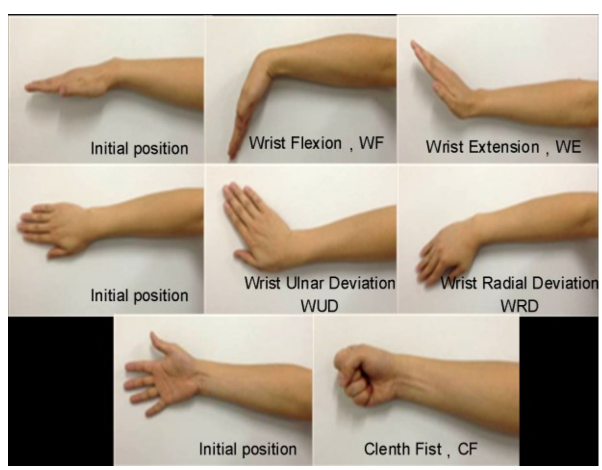

Figure 1. 5 kinds of defined forearm motions

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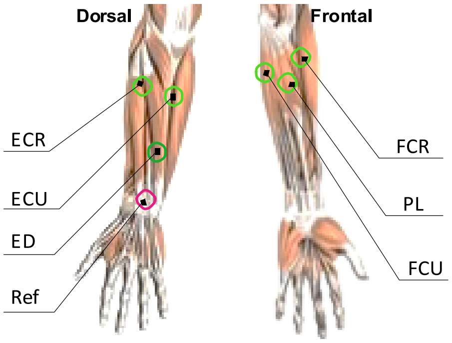
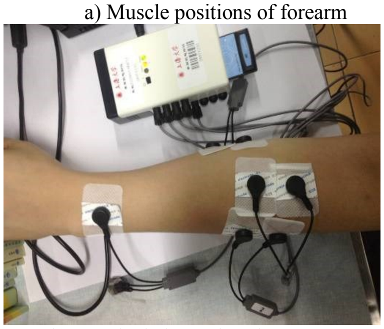
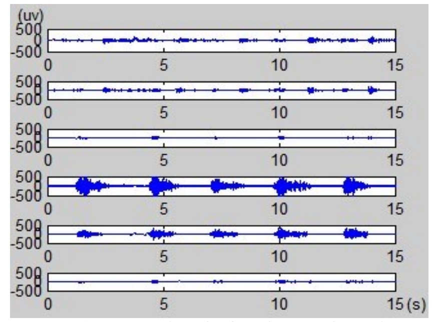


a) Muscle positions of forearm

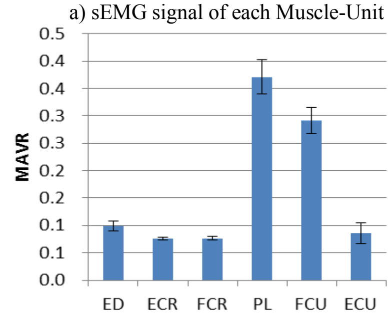


b) Practical electrodes placement

Figure 2. Six-channel electrode placement



a) sEMG signal of each Muscle-Unit



b) MAVR of each Muscle-Unit

Figure 3. The sEMG signal in continuous wrist flexion and the MAVR of each channel

with the experiment process and experimental safety informed.

B. *Electrode sensor placement*

The human forearm muscle group located around the ulnar and radial, according to the depth, can be classified into two layers. Six forearm superficial muscles related to the defined motions mentioned above were selected as the signal source of sEMG, including extensor digitorum (ED), extensor carpi radialis (ECR), flexor carpi radialis (FCR), palmaris longus (PL), flexor carpi ulnaris (FCU) and extensor carpi ulnaris (ECU). Fig.2 shows the position of each muscle in the forearm and practical electrodes placement, and the reference electrode located around the dorsal carpal.

In practical operation, it is difficult to place electrodes accurately to each piece of corresponding muscles for ordinary users without medical knowledge. Therefore, in this experiment, small positional deviation of the electrode is allowed. The regions close to each electrode position, as shown in Fig. 2, are defined as six 'Muscle-Unit' corresponding to respective muscle.

C. *Data acquisition and analysis*

A TeleMyo 2400T-G2 (Noraxon Inc.) sEMG signal acquisition device, which supports 16-channel sEMG signal acquisition, was used in the experiment. 6 channels of the device were used with 1500Hz sampling frequency. The disposable Ag/AgCl patch electrodes were attached to the Muscle-Units.

Usually, a specific motion is not performed by one muscle but the result of comprehensive effect by multiple muscles. For example, Fig. 3 shows the sEMG signal of a certain subject taking wrist flexion continuously. For the defined six Muscle-Units, the sEMG signal from the PL Muscle-Unit and FCU Muscle-Unit are much more obvious than the others. Hence, the six Muscles-Units can be classified into 'major Muscle-Unit' and 'minor Muscle-Unit' according to the correlation between different motions and the corresponding Muscle-Units.

The mean absolute value (MAV) of the sEMG signal amplitude is an important time-domain feature [9]. The calculation of MAV is shown in (1).

$$MAV_m = \frac{1}{N}\sum_{i=1}^{N}\left|A_m(i)\right| \tag{1}$$

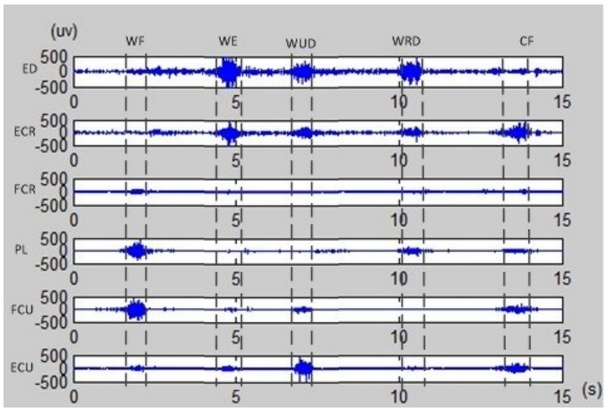
Where N is the sampling number within the active segment of the raw sEMG signal, and $A_m(i)$ is the amplitude of sEMG signal from m Muscle-Unit.

Due to human physiological differences, such as age or physical strength, the MAV of sEMG signal are different. In order to eliminate the influence of physiological differences, MAV ratio (MAVR) of each Muscle-Unit is used in this paper as the parameter for the classification of major and minor Muscle-Units, as shown in (2).

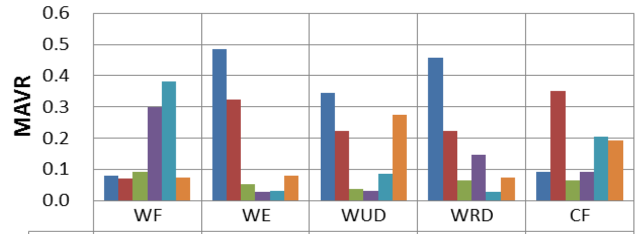
$$MAVR_m = MAV_m \Big/ \sum_{m=1}^{6} MAV_m \tag{2}$$

MAVR for the active segment of sEMG signal can reflect the correlation between different Muscle-Units and one specific motion. The classification steps of major and minor Muscle-Units are as follows: First, calculating MAVR of each Muscle-Unit according to (2). Then, a threshold is used for classification. The major Muscle-Unit is classified if the MAVR is above the threshold, otherwise, the minor Muscle-Units.

In the experiment, data of healthy arms from all the subjects were processed to obtain the motion pattern of the



a) sEMG signal with different motions



	WF	WE	WUD	WRD	CF
ED	0.082	0.485	0.346	0.458	0.093
ECR	0.073	0.322	0.224	0.222	0.351
FCR	0.092	0.052	0.039	0.066	0.067
PL	0.298	0.029	0.031	0.148	0.093
FCU	0.381	0.031	0.087	0.030	0.204
ECU	0.074	0.081	0.274	0.076	0.192

b) MAVR of each Muscle-Unit with the specific motion

Figure 5. Classification of the major and minor Muscle-Units in all motions

Muscle-Units, and the pattern can be used as a reference for exercise therapy with the paralyzed arms of patients.

D. *Virtual interaction*

For patients with severe hemiplegia, traditional method of rehabilitation is hands-on training by therapist. In order to improve the interest and positivity of patients, we established a PC-based virtual interactive training platform used for exercise therapy. The sEMG signal collected from the Muscle-Units was transmitted to PC with the processing of amplification and A/D conversion. Virtual scenes based on DirectX were developed for interacting with patients, and the processed sEMG signal was used to control the movements of the objects in the scenes. In the interaction with the specific motion, a moving average algorithm was applied to the raw sEMG signal, as shown in (3). The result was used as the energy for controlling the movements of virtual objects.

$$E(t) = \sum_{m=1}^{M} \left(\frac{1}{W} \sum_{i=t-W+1}^{t} \left|A_m(i)\right|\right) \qquad t \geq W \qquad (3)$$

Where M is the number of major Muscle-Units, and W is the size of window used in moving average algorithm.

The sum energy of related major Muscle-Units is selected as control signal, as the sEMG signal from the muscles is so weak in the early stage of rehabilitation for severe hemiplegic patients. When the rehabilitation comes to a certain stage, the training can be focused on the dysfunctional Muscle-Units.

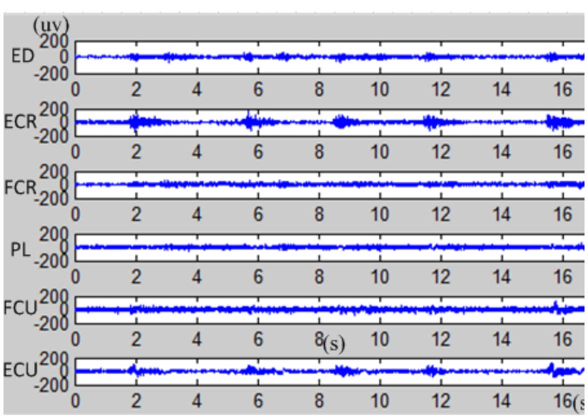


Figure 4. The sEMG signal of WUD motion from a Brunnstrom IV patient

III. EXPERIMENTS AND RESULTS

A. *Differences between healthy people and patients*

Hemiplegic patients are generally older, and compared with healthy people there are some differences in EMG signal strength due to the physiological condition. In the experiment, the max sEMG signal amplitude sampled from the healthy arms of hemiplegic patients is around 250 μ V, while the value form healthy people can reach more than 400 μ V. The sEMG signal amplitude of the paralyzed arm is also lower than the healthy arm for one patient, as shown in Fig. 4. Meanwhile, due to spasms or synkinesis of muscles, the signal features from 6 Muscle-units are different between the paralyzed arm and the healthy one. In the subjects, Brunnstrom I hemiplegic patients with completely paralyzed forearm muscles, are difficult to collect effective sEMG signal. Therefore, the study of this paper mainly applies to patients at Brunnstrom II or above.

B. *Major Muscle-Units related to motions*

Fig. 5 shows the sEMG data from one subject who completed all the defined motions in sequence. According to the classification method of major and minor Muscle-Units in the experiment, the MAVR of all Muscle-Units in various motions can be calculated, and obviously differences between major and minor Muscle-Units in each action can be seen in Fig. 5 b). For example, taking the MAVR rate of 0.1 as the threshold, the major Muscle-Units related to the wrist flexion are PL and FCU, while these related to the wrist extension are ED and ECR. Similarly, the same test was carried out with healthy arms of all the subjects, and the statistical data indicates that major Muscle-Units of different people in specific actions have consistency. The statistical results of major Muscle-Units related to each specific action are shown in Table I.

According to the correspondence between motions and major Muscle-Units listed in Table I, more targeted adjunctive therapy, such as functional electrical stimulation (FES), can be applied to the dysfunctional muscles of Hemiplegic patients.

C. *Training application*

In the experiment, several hemiplegia patients participated in the test of virtual interactive training platform. Fig. 6 shows one of the patients (Brunstrom II) taking the clench fist

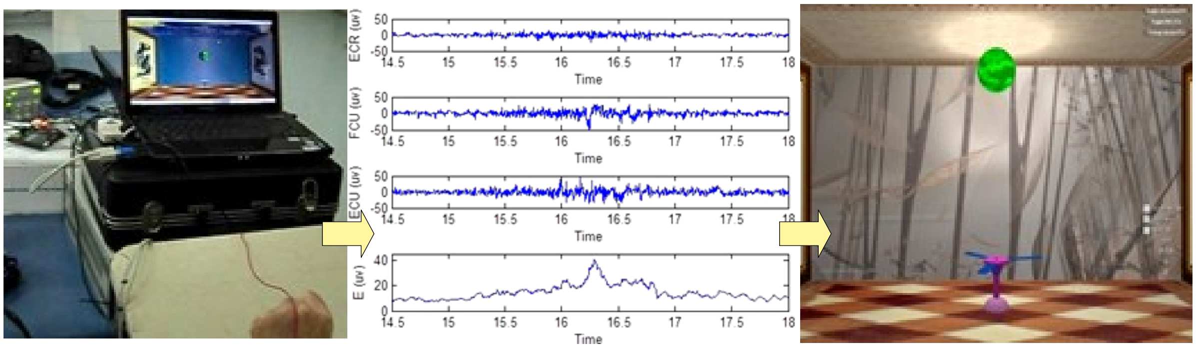


Figure 6. Training sample of a Brunnstrom II patient with clench fist

training. Electrodes were placed on main Muscle-Units related to the motion: ECR, FCU and ECU, and the window size used in average moving algorithm was 96 sampling points. The virtual scene for interaction on PC client was composed of a fan and a floating ball, mainly used for muscle strength and endurance training. The training process can be described as follows: at the beginning, the fan and ball being stationary while patients keep relaxed state and taking the max value of the energy from main Muscle-Unit as the excitation threshold. Then, the dynamic energy value will exceed the excitation threshold with contraction of muscles, which promote the ball to rise with the rotation of the fan. Finally, when the ball reaches the predetermined height, patients need to maintain muscle contraction for a period of time until the ball is lighting, and then the training is completed. Through the experiment, this training method can greatly stimulate the interest and positivity of patients, and achieve better training results for patients at Brunnstrom II or above. However, due to the extremely weak sEMG signal, patients at Brunnstrom I could not adapt to this training method.

TABLE I. THE MAJOR MUSCLE-UNITS RELATED TO SPECIFIC MOTIONS

Motion	Major Muscle-Unit
Wrist Flexion	PL, FCU
Wrist Extension	ED, ECR
Wrist Ulnar Deviation	ED, ECR, ECU
Wrist Radial Deviation	ED, ECR, PL
Clench Fist	ECR, FCU, ECU

IV. CONCLUSION

The sEMG signal plays an important role in the research of gesture recognition and rehabilitation training, and more information of the muscles can be obtained with the increase of channels. However, in practical applications, excessive channels and muscle positions could cause distress in patients with no medical experience. By the experimental results of this paper, it is convenient for practical use within 3 electrode channels when the patients were in specific motion training. For patients with severe hemiplegia who are unable to perform the specific motions, the adjuvant therapy using FES to related Muscle-Units could be taken. The rehabilitation training method for patients with severe hemiplegia mentioned in this paper, its actual effectiveness still need clinical validation of a certain period of time.

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