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Corticomuscular Coherence Analysis on The Static and Dynamic Tasks of Hand Movement

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Abstract—The synchronization between cortical motor and muscular activity can be revealed by corticomuscular coherence (CMC). This paper designed two neuromuscular activity paradigms of hand movement, i.e. static gripping task and dynamic finger moving task. The electroencephalography (EEG) from C3 and C4 channels and the surface electromyography (sEMG) from the flexor digitorum superficialis were collected simultaneously from 4 male and 4 female right-handed healthy young subjects. For the static gripping task, CMCs during low-level forces under 4%, 8%, and 16% MVC (Maximal Voluntary Contraction) were investigated by using magnitude squared coherence calculated from EEGs and sEMGs. For the dynamic finger moving task, the time-frequency domain analysis was used to process dynamic data of temporary action in a period of 2 seconds and get the latency of the maximum CMC. The results of this study indicated that the force increasing within the low-level range in static task is associated with the enhanced CMC. The maximum amplitude of CMC occurred about 0.3-0.5s after the onset of hand movement. Subjects showed significant CMC performance both in static and dynamic task of hand movement.

Keywords—corticomuscular coherence; flexor digitorum superficialis; magnitude squared coherence; time-frequency domain analysis

I. INTRODUCTION

It is a well-known phenomenon that oscillatory activity in the frequency range of 15-35Hz occurs in sensorimotor cortex of human's brain. These oscillations are synchronized to activity in motor units. The synchronization between cortical motor and muscular activity can be revealed by CMC [1]. Over the past 20 years, an increasing number of scholars and institutions paid close attention to the research of human's CMC. In Conway's study, they proved motor unit and cortical neurons discharged synchronously under sustained contraction force, and beta-band CMC occurred between muscles and contralateral motor cortex [2]. Wolfgang found that CMC occurred in beta-band under the static low-level force. However, with force increasing, the CMC tends to move to gamma-band [3]. In addition, Perez showed fine movement help increase the amplitude of CMC [4].

As fine motor can improve the coherence between muscle and motor cortex [5] [6] [7] [8], previous studies in humans investigated hands movement of low-level forces around a fixed value, and they also suggested that dynamic force regulation using single or multiple fingers could be attributed

to neuromuscular communication [9]. However, few of them investigated the correlation between CMCs in different MVC levels [10] [11] [12], and the latency of CMC during dynamic task was also neglect. In addition, although a lot of research investigated CMC under static and dynamic force, few of them combined these two task models together on the same subjects. In view of these, this paper designed two tasks, i.e. static gripping task and dynamic finger moving task, for the same subjects, aiming to investigate the characteristics of CMCs in different static low-levels of gripping force and the latency of maximum amplitude of CMC in dynamic finger movement.

This paper is organized as follows. Section II addresses the methodology including the visual feedback system, experimental setup and signal processing. Section III shows the results of two experimental paradigms. The conclusion is stated in Section IV.

II. MATERIALS AND METHOD

8 healthy subjects (4 females) between 22-25 years old participated in the experiments. The subjects were right-hand users without limb movement disorder or history of mental illness.

All subjects were in good spirits on the day of experiment. In addition, no subjects were trained before taking part in these two experiments. All subjects gave written informed consent after the natural and possible consequences of the study were explained.

The experiment was undertaken in the quiet environment without electromagnetic interference. During the experiment, the subject was required to remain seated stably, hold the dynamometer in the right hand.

A. The visual feedback system

Static grip visual feedback system: Displayed on LabVIEW, where every cell in the abscissa represents one second, and the ordinate represents the value of grip (Volt). If a subject's 16% MVC is 0.1V displayed on LabVIEW, he or she should stabilize the curve around 0.1V by adjusting the gripping force.

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Dynamic finger moving vision feedback system: A continuous square signal with pulse period of 2 seconds and duty ratio of 40% was displayed on LabVIEW window.

B. Experimental paradigm

Rest modal: At the beginning of the experiment, subjects kept in quiet state. Signals of C3, C4 and other leads of EMG were recorded for 60 seconds simultaneously.

Static grip task modal: Flexor digitorum superficialis was the target muscle. MVC was measured for every subject before the experiment. During the measurement, subjects were required to grip the dynamometer using his or her maximum myodynamia in the right hand assisted by the left hand and held it for 4 to 5 seconds. The subject was not allowed to use his or her explosive power and required to repeat this procedure three times, between which there is a rest to prevent the muscle fatigue. The maximum value of the grip power was regarded as the MVC. In the following experiments, the subject should reach his or her 4%, 8%, and 16% MVC.

Based on the experiment paradigm of Witte M et al. [12], this paper designed three static gripping tasks which were 4% MVC, 8% MVC and 16% MVC. Every task included three sessions with the same grip power level, and every session lasted for ten minutes including several trials. The lasting time of every trail was controlled by the subject him or herself. Within one trial, the gripping task should last 4 to 5 seconds; subject could take a break in 5 to 10 seconds to prevent the muscle fatigue [12]. Between sessions, subjects had a rest of ten minutes. The temporal evolution of one session in gripping task is shown as Fig. 1.

According to measured MVC (corresponding to the display of LabVIEW window), the value of 4% (8%, 16%) MVC can be calculated, and displayed on the window of LabVIEW. The subject should keep his or her eyes on during the procedure of gripping the dynamometer to keep the grip power stable around the 4% (8%, 16%) MVC.

Dynamic finger moving task modal: The task included two sessions, and each session included 60 trails. In every trail, the subject extended his or her index finger when the rising edge of the square signal appeared, and maintained the extension until the falling edge of the square signal appeared. The pulse period of the square signal was 2 seconds and the duty ratio was 40%.

C. Recording

EEG electrodes from company Neuroscan were pasted to the position of C3, C4 and A2 (mastoid of right ear as the reference electric potential), referring to the international standard pasting position with 10-20 electrodes as Fig.2. shows. In addition, the flexor digitorum superficialis of the subject should be polished with scrub cream before data collection. The resistances of the electrode patches were kept

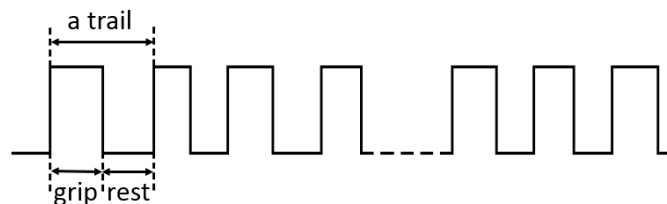


Figure 1. The temporal evolution of one session

under 5KΩ.

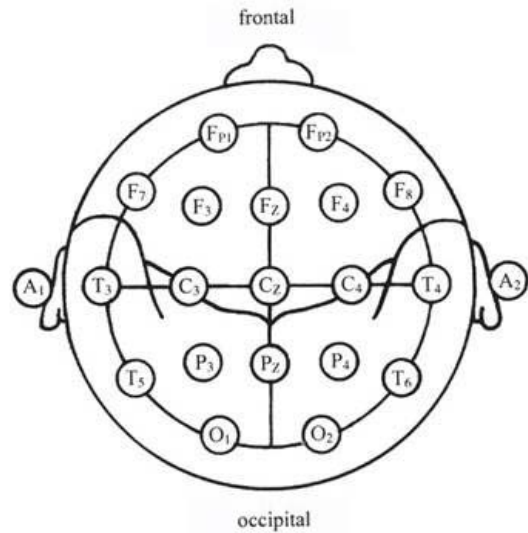


Figure 2. EEG measurement electrode positions

D. Signal processing

The sampling frequency was 1000Hz. EEG data was 5-60Hz band-pass filtered and EMG data was 15-200Hz band-pass filtered. EMG signal was rectified as it is known that full wave rectification provides the temporal pattern of grouped firing motor units. [8] [13].

To avoid transient effects, data related to the force ramp phase were not dealt with in this study. The steady gripping signal was extracted from each trail and then spliced for a new continuous data which was further divided into successive segments of 512ms, allowing for a frequency resolution of 1.96Hz.

The CMC calculated by the magnitude squared coherence which defined as

$$Coh_{c1,c2} = \frac{|S_{c1,c2}(f)|^2}{|SP_{c1}(f)| \times |SP_{c2}(f)|}, \quad (1)$$

To make the result of the experiments meaningful, Rosenberg JR et al. proposed confidence level (CL) equation defined as (2) in 1989 [14],

$$CL(\alpha) = 1 - (1 - \alpha)^{\frac{1}{n-1}}, \quad (2)$$

where n is the number of segments and α is the desired level of confidence. We considered coherence to be significant when it was above the CL.

Based on Continuous Wavelet Transformation (CWT), time-frequency domain analysis of CMC was defined as

$$Coh_{c1,c2}(\tau, f) = \frac{|S_{c1,c2}(\tau, f)|^2}{|SP_{c1}(\tau, f)| \times |SP_{c2}(\tau, f)|}, \quad (3)$$

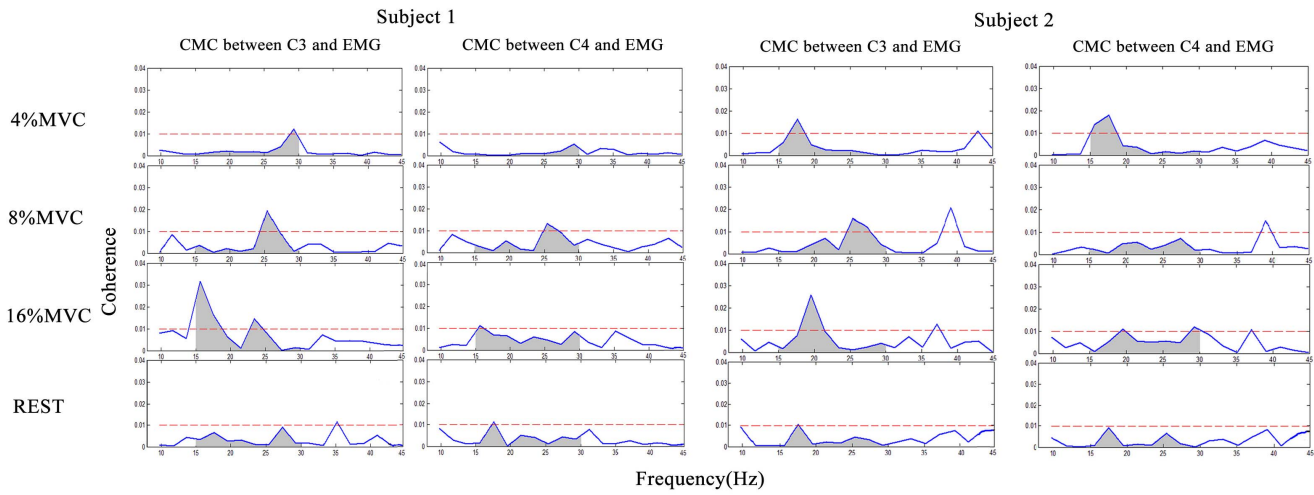


Figure. 3 Two typical subjects' CMC

where

$$S_{c1,c2}(\tau, f) = \frac{1}{n} \sum_{i=1}^n C1_i(\tau, f) C2_i^*(\tau, f), \quad (4)$$

$SP_{c1}(\tau, f)$ and $SP_{c2}(\tau, f)$ are the power spectra for channels $c1$ and $c2$ at a given frequency f . $C1$ and $C2$ are the CWT data of channel $c1$ and $c2$ in a given segment i ($i=1 \dots n$) and '*' indicates the complex conjugate. $S_{c1,c2}(\tau, f)$ is the cross-spectrum for EEG (channel $c1$) and the rectified EMG (channel $c2$) at a given frequency f .

The spectral power (SP) for a given channel (c) was derived using

$$SP_c(\tau, f) = \frac{1}{n} \sum_{i=1}^n C_i(\tau, f) C_i^*(\tau, f), \quad (5)$$

where C_i represents the CWT data of channel c for a given segment i and '*' indicates the complex conjugate.

III. RESULTS

Early research proposed that not everyone showed the CMC [15]. In our experiment, 4 subjects of 8 presented CMC in static gripping task modal. After static task, subjects were divided into the group 1 (showed significant CMC performance) and group 2 (showed no significant CMC performance) to participate in dynamic task. Subjects who showed significant CMC in static task also showed it in dynamic finger moving task.

A. Static grip experimental modal

The CMC was significant only if its amplitude is bigger than CL (the red dotted line in Fig. 3). As Fig. 3 shows, CMCs mainly concentrate on beta-band, the maximum amplitude of CMC in C3 is stronger than that in C4 which shows almost no significant amplitude.

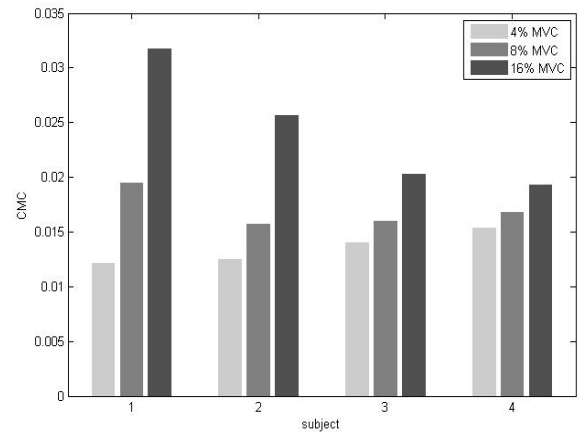


Figure. 4 The maximum amplitude of CMC between C3 and EMG under 4%/8%/16% MVC

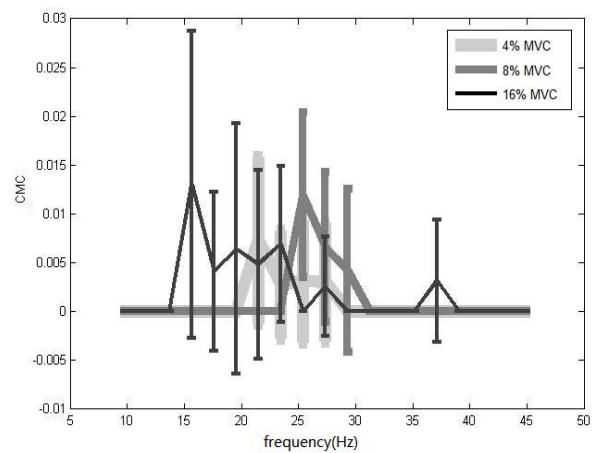


Figure.5 The averaged CMC for 4 subjects

In addition, the maximum amplitudes of CMC are compared in Fig.4. Under low-level force [13], as the force increases (4% MVC to 8% MVC to 16%MVC), the maximum amplitude of CMC tends to increase, which indicates that the force increasing within the low-level range in static task is associated with the enhanced CMC.

Setting the amplitude of CMC under the *CL* zero, the CMC amplitudes of 4 subjects were averaged. As Fig.5 shows, the CMC maximum amplitudes in three level force have the same tendency with that in Fig. 4. In addition, compared to 4%MVC, the significant frequency band of CMC of 16% MVC is wider.

B. Dynamic finger moving experiment modal

To find the latency of CMC, time-frequency domain analysis was performed. As Fig. 6 shows, the CMC in C3 is obvious and mainly concentrates in beta-band. However, there is almost no CMC in C4. The important information about the latency of the maximum CMC can also be gotten. The white lines in Fig. 6 represent the beginning time of action. The maximum amplitudes of CMC occur about 0.5s after the onset of movement. Four subjects' maximum CMCs of C3 in dynamic finger moving experiment are analyzed as Fig. 7 shows. Each of the 4 subjects repeated this task twice. The latency and frequency of the maximum CMC concentrate in 0.3s-0.5s and 20-30Hz.

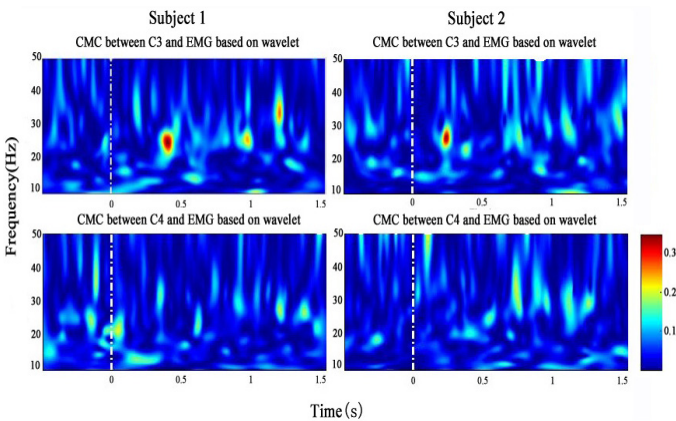


Figure 6 CMC based on CWT

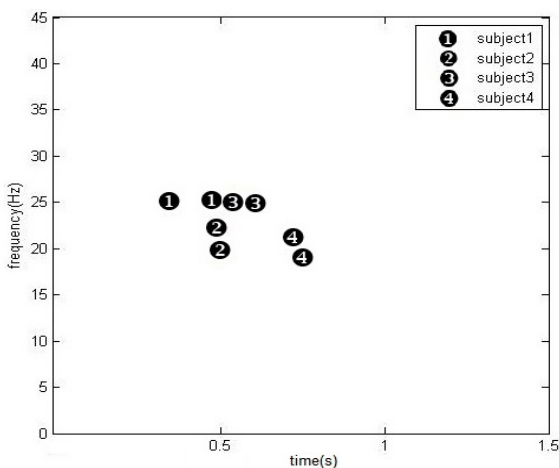


Figure 7 Time and frequency statistic for 4 subjects

IV. CONCLUSIONS

This work combined two experimental paradigms of hand movement to investigate CMC. The result indicated that the force increasing within the low-level range in static gripping task is associated with the enhanced CMC. Subjects who showed CMC performance in static grapping task could also show it in dynamic finger moving task. The latency of maximum CMC is approximately 0.3-0.5s after finger moving.

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