EFFECTS OF EXTERNALLY APPLIED ELECTRICAL STIMULUS ON BRAIN-MUSCLE RELATIONSHIP DURING ISOMETRIC CONTRACTION OF HAND MUSCLE

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To my beloved parents and families

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ABSTRACT

Communications exists between the peripheral muscles and the sensorimotor cortex, which controls the movement functions in the brain. There are five brain's natural oscillations classified as delta, theta, alpha, beta and gamma which governed most general dynamics in the brain. It is proven that increased alpha activity can be expected in situations or tasks in which attentional demands require inhibition of non-task relevant processes. Recently, study on effects of counting or ignoring externally applied electrical stimulus while performing motor task has shown that cortico-muscular coherence in the beta band during isometric hand contraction can be enhanced by a electrical stimulus unrelated to the motor task. The finding suggests that cognitive effort is needed to maintain isometric muscle contraction. Since cognitive effort involves functional connections between different brain regions in the brain, further studies are needed to clarify these functional connections between different brain regions. By exploring the C_3-EEG coherence, this project study the functional connection between different brain regions and in addition, measure speed of information transfer between brain areas.

ABSTRAK

Komunikasi wujud antara otot dan sensorimotor korteks, yang mengawal fungsi pergerakan di dalam otak. Terdapat lima kumpulan gelombang semulajadi otak dikategorikan sebagai *delta*, *theta*, *alpha*, *beta* dan *gamma*, yang memberikan arahan kepada hampir keseluruhan daya gerak di dalam otak. Telah dibuktikan bahawa peningkatan aktiviti *alpha* akan berlaku dalam situasi atau tugasan yang memerlukan perhatian bagi menghalang proses atau kawasan yang tidak releven. Baru-baru ini, kajian tentang kesan menghitung atau mengabaikan ransangan elektik yang diberikan dari luar sambil melakukan pergerakan telah menunjukkan bahawa koherens antara otak dan otot dalam gelombang *beta* semasa pengecutan isometrik tangan boleh ditingkatkan oleh ransangan elektrik yang tidak berkaitan dengan pergerakan tersebut. Ini menujukkan bahawa daya kognitif diperlukan untuk mengekalkan pengecutan isometrik otot. Memandangkan daya kognitif melibatkan perhubungan antara bahagian otak yang berlainan, kajian lanjut diperlukan untuk menjelaskan perhubungan ini. Dengan mengkaji pertalian C_3-EEG, projek ini mempelajari pertalian antara bahagian otak yang berlainan dan sebagai tambahan, mengukur kelajuan penghantaran informasi antara bahagian-bahagian otak.

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LIST OF ABBREVIATIONS

ADC - analog-to-digital converter
CNS - central nervous system
CSD - current source density
DFT - discrete Fourier Transform
EEG - electroencephalography
EMG - electromyography
ES - electrical stimulus
FDI - first dorsal interosseous
FFT - fast Fourier transforms
IFFT - inverse Fourier transformation
ISI - inter-stimulus-interval
LSR - least squares regression analysis
MAX-COH - maximum coherence
MEAN-COH - mean of significant coherences
MEG - magnetoencephalography
MVC - maximum voluntary contraction
PMC - premotor cortex
PNS - peripheral nervous system
PTNs - pyramidal tract neurons
SCDs - scalp current densities
SEM - standard error of the mean
SMA - supplementary motor area
SPs - scalp potentials
WLSR - weighted least squares regression analysis

CHAPTER 1

INTRODUCTION

1.1 Introduction

Voluntary movements involve the cooperation of many muscles. Communications are believed to exist between the peripheral muscles and the sensorimotor cortex, which controls the movement functions in the brain. During voluntary activity in humans, motor units are exposed to a number of descending drives that tend to synchronize motor unit activity at particular frequencies. In particular, the contralateral motor cortex drives muscle discharge in the beta (15-30Hz) and Piper (30-60Hz) bands. The cortical activity in these bands is task specific, somatopicly distributed and generally precedes muscle discharge by an interval appropriate for conduction on fast pyramidal pathways. Coherence between cortex and muscle in the beta band is found during isometric contraction of weak and moderate strengths. Thus oscillations within the beta band seem to coincide with the stable, relatively immutable state – a free running mode of the motor cortex that may maintain stable motor output with a minimum of computational effort. Magnetoencephalography (MEG) and electromyography (EMG) show significant coherence in the frequency band 15-35 Hz of measurements of the first dorsal interosseous (FDI) hand muscle [1].

A direct cortical drive to muscle should be associated with lags between muscles comparable to those seen after transcutaneous magnetic stimulation of the motor cortex, which is known to involve fast pyramidal pathways [2]. Other authors have found that EMG lags cortical activity in both beta and Piper bands, and that the difference in lag between muscle is consistent with conduction down fast pyramidal pathways [3]-[5]. The MEG-EMG phase depends linearly on frequency in the frequency range with significant coherence. This confirms the interpretation of a fixed delay between the MEG and EMG signals. The absolute lags between cortex and muscle is difficult to settle. Although the rank ordering in MEG-EMG delays between hand and foot muscles corresponds to differences in conduction times, the absolute latencies determined from cross-correlograms (3-8ms for the first dorsal interosseous, 17-25 ms for tibialis anterior) are much shorter than would be expected for conduction in pyramidal pathways. Such short latencies could, in principle, be explained if both the cortical and the spinal level were driven by a common input. Literature on time delay is vast and well documented in [6]-[7].

1.2 Experimental Procedures of Previous Project [8]

1.2.1 Materials and Methods

The data were obtained through the experiment carried by Norlaili Mat Safri [8]. In this experiment, 7 right-handed subjects participated, aged 20-24 years old. The international 10-20 electrode placement method was used with 19 electrodes placed on the scalp for capturing EEG signals (MME-3124; Nihon Kohden, Tokyo, Japan). Surface EMG was recorded from the first dorsal interosseous (FDI) muscle of the right hand with reference to the head of the second metacarpal bone of the index finger (Figure 1.1). EEG and EMG signals were stored in a personal computer with a sampling frequency of 1000 Hz and recorded with passbands of 0.5-200 Hz and 5-500 Hz, respectively, when subjects made weak isometric contraction. EMG signals were then rectified and used for the analysis.

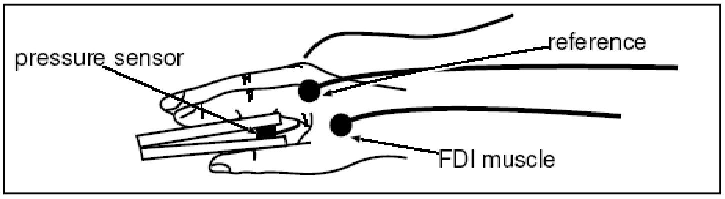

Figure 1.1 The pressure measurement [adapted from 8]

Four trials were performed for each task, in which a single trial lasted for 1 minute. Before each run, each subject’s maximum voluntary contraction (MVC) and threshold voltage was optimized to maintain weak contraction and fixed the inter-stimulus-interval (ISI) throughout the experiment. The procedures to get the values are explained in the next paragraphs.

Subjects were asked to hold a device with a force gauge sensor at its center between the thumb and the index finger, and to squeeze the device to cause a weak contraction, ~10% of MVC. The MVC force level was displayed via a digital display (NMB CSD-815 Digital indicator; Minebea Co. Ltd), recorded and repeated for five times. The average of these MVC force level was taken as the MVC force level for the subject giving 61 ± 5 N (mean ± standard error of the mean [SEM]; n=10).

The ISI was fixed at 1 Hz and the intensity of the electrical stimulus was set at 1.5 times bigger than the threshold. To find the threshold voltage, first, electrical impulse was given to subject at a random intensity. If subject could felt the electrical impulses, the intensity was reduced until subject could no longer felt the electrical impulses. The new intensity then became the threshold voltage for the subject. The threshold voltage varied among subjects and within subject's bilateral third fingers. Experiments were done to delineate the effects of electrical stimulus with ISI fixed at 1 Hz.

Four different experimental conditions were investigated in a given recording session.

Control task:	Subjects had to pay attention and perform the motor act with the gazed fixed on the FDI muscle. Motor act was maintained for the entire recordings. This Control task was done before and after each Electrical Stimuli -Ignore (ES-Ignore), -CountRight (ES-CountRight) and -CountLeft (ES-CountLeft) task.
ES-Ignore task:	In this task, electrical stimulus was given at subjects bilateral hand's third fingers in random sequence with ISI 1 Hz. Subjects were told to ignore the presented stimulus, while at the same time, perform the motor act as in Control task.

ES-CountRight task: The procedures and settings were the same as the ES-Ignore task, except to count the number of stimulus given at the right hand only, and concurrently, maintain the FDI muscle contraction for the entire recordings.

ES-CountLeft task: The procedures and settings were the same as the ES - Ignore and -CountRight tasks, except to count the number of stimulus given at the left hand only, and concurrently, maintain the FDI muscle contraction for the entire recordings.

Figure 1.2 shows the measurement system of “electrical stimulus" (ES) tasks, while Figure 1.3 shows the task sequence.

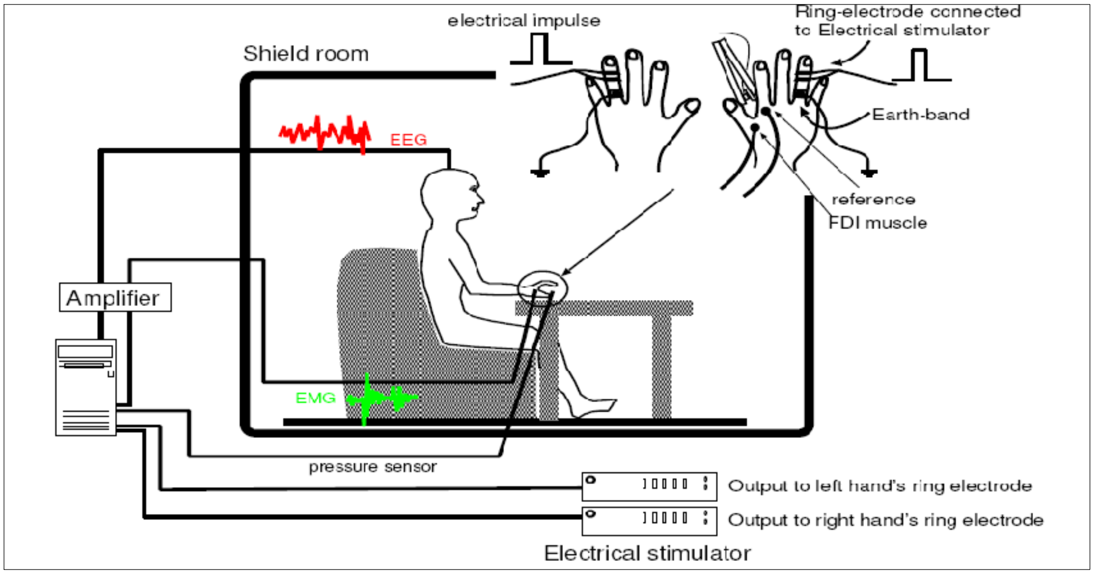

Figure 1.2 Experimental setting for recording of EEG and EMG for “electrical stimulus" (ES) tasks [adapted from 8]

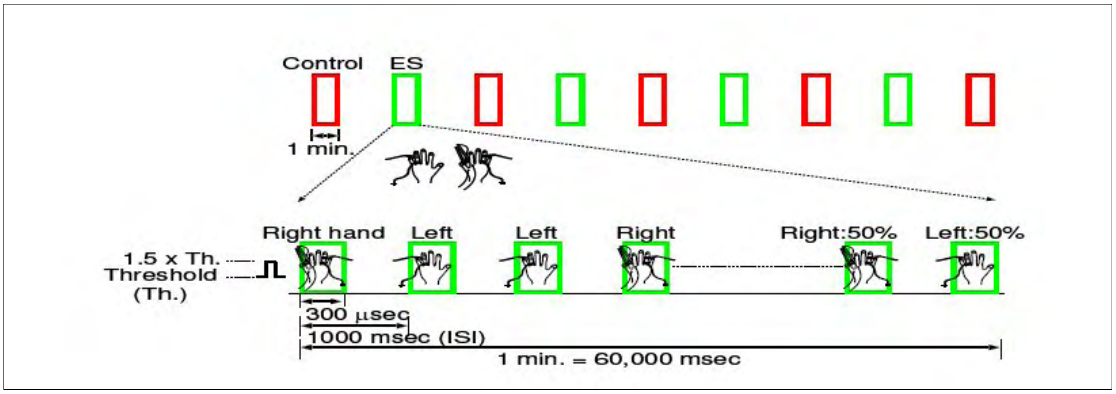

Figure 1.3 Task sequence of Control and “electrical stimulus" (ES) tasks [adapted from 8]

1.3 Findings of the Previous Project

Grand averages of 7 subjects were used in each coherence spectrum in all the tasks. Coherence spectra were organized topographically according to the approximate location of the 19 electrodes on the scalp. The horizontal dashed lines indicate the 95% confidence level. The coherence magnitude is significant when it is above the confidence limit. Figure 1.4, 1.5 and 1.6 shows significant magnitude of the coherence was found at the C_3 site, at the beta frequency band. The similar frequency range of the coherence was also seen at the F_3 and P_3 sites for ES-Ignore and –CountRight tasks while seen at the F_3, P_3 and C_z sites for the ES-CountLeft tasks, although the magnitude was smaller than at the C_3 site. The spectral peak at the C_3 site for the ES-Ignore, -CountRight and –CountLeft tasks are slightly higher than the Control task. In the After (Control) task, the spectral peak decreased back to value near the Control Task, showing the recovery.

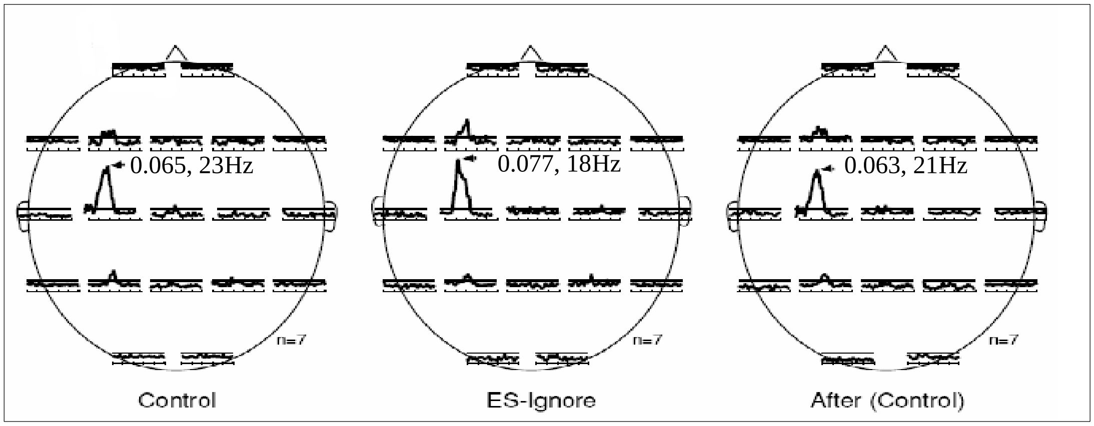

Figure 1.4 Mean coherence spectra between the EEG and EMG (FDI) signals for ES-Ignore Task [adapted from 8]

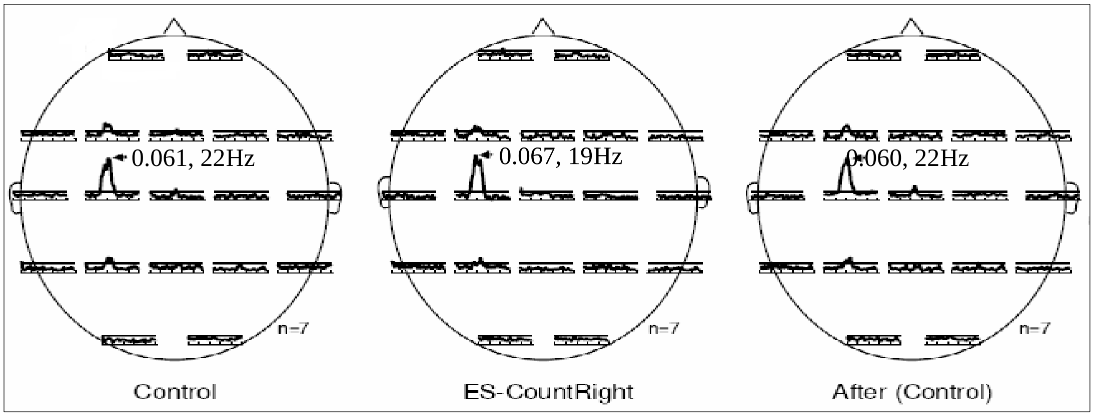

Figure 1.5 Mean coherence spectra between the EEG and EMG (FDI) signals for (ES)-CountRight task. [adapted from 8]

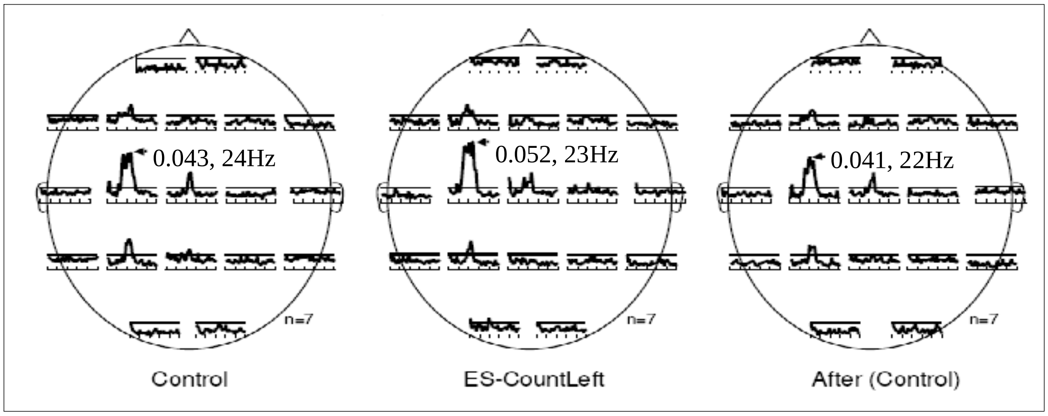

Figure 1.6 Mean coherence spectra between the EEG and EMG (FDI) signals for ES-CountLeft task. [adapted from 8]

The major finding of this study is that the cortico-muscular coherence during the isometric hand contraction can be enhanced by the electrical stimulus unrelated to the motor task. Since such an electrical stimulus is thought to act as a disturbance against the motor task, one would think that the motor task can be interfered, and/or the magnitude of coherence can be declined, by the electrical stimulus. However, the results of this experiment have shown the opposite of this view. This provides an additional aspect for cross-modal modulation of the functional coupling between the muscle and the sensorimotor cortex in humans.

1.4 Problem Statement

Generally, coherence size (magnitude) and time delay (phase shift) are investigated to reveal communication between the human motor cortex and muscle. In the previous study, the beta frequency band synchronization between the motor cortex and the motor muscle is sustained/enhanced during isometric contraction in the presence of somatosensory stimulation (via electrical pulses). It is also found that the level of sensitivity towards tactile stimulus also influence the synchronization.

However, in the previous study, the brain region connectivity and its temporal relationship during somatosensory stimulation are not addressed yet. By using the EEG-EEG coherence, it is able to configure if direct relationship exists between each brain region and the C_3 site. C_3 site was chosen as the reference point, since significant magnitude of the brain-muscle coherence was found at the C_3 site, at beta frequency band during the isometric hand contraction. In the other hand, EEG-EEG temporal analysis can be done using many time delay estimation methods available for investigating their physiological significance.

1.5 Objectives

The main objective of this project was to investigate the effects of externally applied electrical stimulus on brain muscle relationship during isometric contraction of FDI muscle in terms of:

1. Inter-relationship between brain region
2. Temporal brain region relationship

1.6 Project Scope

Previously, electroencephalograph (EEG) and electromyograph (EMG) activities from the first dorsal interosseous (FDI) muscle of the right hand were recorded in seven subjects performing four different tasks.The project was continued by studying the time delay between EEG(C_3)-EEG signals to establish the temporal relationship between different brain regions and the motor cortex using inverse fast Fourier transforms (IFFT). In the other hand, coherence between the EEG-EEG signals was calculated using spherical splines principle to establish the inter-relationship between brain regions.

The raw binary data were converted into decimal and processed to attain the coherence value using the spherical splines principle. The current source density (CSD) reference values were estimated and used in the phase and temporal analysis. In order to study the data signal for its frequency content, they were converted from time domain into the frequency domain. This was accomplished by applying a mathematical method known as fast Fourier transforms (FFT).

To perform the analysis, C programming language was used. The result is then mapped following the location of the site so as to make the analysis part of verifying the functional connectivities of different region easier to discuss. To support the findings, the frequencies were grouped into five types of EEG band, Delta, Theta, Alpha, Beta and Gamma band.

1.7 Project Contribution

Analysis of the EEG-EMG coherence can provide a useful tool for understanding the corticomuscular functional connection in stroke recovery. The time delay between two dynamical systems can provide information on conduction velocity, and the nature and origin of coupling, between the processes. From this study a better understanding of how the human brain transforms sensory signals into appropriate motor output and how different perceptual and attentional factors influence this transformation are gained. The present study provides an approach to investigate the loci associated with tactile-motor processing and to measure the task-specific effect of stimulus predictability on network components.

1.8 Thesis Outline

This report consists of 6 chapters as follows:

Chapter 1: This chapter is on the introduction which includes the project background, problem statement, objectives and scope of the project, and the project contribution.

Chapter 2: This chapter provides literature review on neural systems especially on somatic sensory cortex, motor cortex muscle and cortical electrical rhythm. Data acquisition and processing was also discussed by providing relevant procedures and formulas.

Chapter 3: This chapter describes the project methodology by giving details on the flow of calculation involved to establish the objectives.

Chapter 4: This chapter presents the result and findings on coherence and cross-correlation between brain regions.

Chapter 5: This chapter discusses further the result and findings, which were supported by relevant findings from previous research.

Chapter 6: This chapter concluded the findings by answering the objectives.

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