CORTICOMUSCULAR COHERENCE AFTER MUSCLE FATIGUE

Ali A. Abdul-latif 1, Irena Cosic 1, Dinesh K. Kumar 1, Barbara Polus 2, Djuwari Djuwari 1

1 Biomedical Engineering Research Group, School of electrical and Computer Engineering, RMIT University, Melbourne, Australia
2 Clinical Neuroscience Research Group, Faculty of Life Sciences, RMIT University, Melbourne, Australia

Abstract

Functional correlation between two separated neural systems can be studied using coherence function. Coherence function is a frequency domain measurement of similarity and phase lock between two different signals.

The aim of this study is to determine the changes in corticomuscular coherence after muscle fatigue during maximum voluntary contraction (MVC) and 50% of MVC of the tested muscle (right Adductor Pollicis muscles “APM”). Nine right-handed normal volunteers, four women and five men, whose age was 35±12 years (SD) were studied.

Maximum coherence values of (0.041) at 38 Hz. (in gamma band) were seen in non-fatigued MVC; and values of (0.042) at 32 Hz and 34 Hz. (in gamma band) for fatigued MVC of right APM were demonstrated.

During 50% of MVC of right APM (in non-fatigued contraction), maximum coherence value of (0.044) at 26 Hz (beta band) is noted. In fatigued 50%MVC, maximum coherence value is seen at beta frequency band (0.048 at 14 Hz). These results have demonstrated the functional coupling between the motor cortex and the contracting muscle during fatigued muscular contraction. The pattern of maximum coherence values, which is related to EEG frequency bands, seen in non-fatigued muscular contraction is also demonstrated in fatigued muscular contraction.

Key Words: Signal processing, Corticomuscular coherence, Muscle fatique, Maximum voluntary contraction

Introduction

Voluntary muscular contraction is controlled by the contralateral motor cortex of the brain through descending neural commands, which tend to produce synchronized motor units discharge at different frequencies [1]. The motor cortex can modulate voluntary muscle contraction by changing the firing frequencies of the motor units from low levels of 2Hz and up to a little higher than 50Hz [2, 3].

The central neural control mechanism (or mechanisms) of voluntary muscular contraction is still not fully understood 1. In the recent years there are considerable interest in the functional correlation between the neural electrical activity of the motor cortex and the electrical activity associated with different levels of muscular contraction as an indication of the physiological bonding between them [4, 5, 6, 7].

Functional correlation between two separated neural systems can be studied using coherence function [8, 9, 10, 11, 12]. Coherence function is a frequency domain measurement of similarity and phase lock between two different signals. It differs from cross spectrum analysis in that it is normalized to produce values between zero and one, where zero indicates totally unrelated signals, and one indicates identical signals [12]. It is a tool that can measure the degree to which different neural structures show functional correlation in different frequency bands [9].

In 1995, Conway and his colleagues were the first who studied corticomuscular coherence. They used coherence function to demonstrate the functional correlation between magneto-encephalogram (MEG) and electromyogram (EMG). The MEG/EMG coherence during sustained muscular contraction demonstrates that motor cortical activity may influence the timing of motor unit firing. This relationship may represent the binding within the motor system between the central commanding
area, the motor cortex, and the peripheral organ, the skeletal muscle [4].

Halliday and his colleagues showed that corticomuscular coherence associated with muscular contractions can also be demonstrated by using electroencephalogram (EEG) and EMG signals. Both MEG/EMG coherence and EEG/EMG coherence showed that EEG signals in the range of 15-30 Hz, which is called beta rhythms, are correlated with EMG signals in the same frequency ranges during sustained weak-moderate muscular contraction when recorded simultaneously [4, 5, 10]. In a small number of subjects corticomuscular coherence has occurred at around 40 Hz (30-60 Hz, Gamma waves) during weak-moderate muscular contraction [14]. Typically corticomuscular coherence in gamma band of EEG (30-60 Hz) is observed during strong muscular contraction (more than 60% of maximum voluntary contraction, MVC) [1, 9]. The magnitude of corticomuscular coherence is approximately 0.02-0.15 for MEG/EMG studies and 0.02-0.33 for EEG/EMG studies and these values are not significantly different among different tested muscles [9].

Literature reviews have showed that there is no published article studying EEG/EMG coherence after muscle fatigue. The aim of this study is to determine the changes in corticomuscular coherence after muscle fatigue during MVC and 50% of MVC of the tested muscle (right Adductor Pollicis muscles “APM”).

**Methods**

**Subjects and Data acquisition:**

Nine right-handed normal volunteers, four women and five men, whose age was 35±12 years (SD) were studied. They were having no history of any neurological, muscular or skeletal disease or disorder. Each subject was under no effect of any medication or substance that can affect his motor performance. The experimental protocol was approved by the Ethics Committee of Faculty of Engineering, RMIT University, and the subjects gave written informed consent for the experiment.

The experiment is designed to record EEG from left motor cortical area (C3, FC3) using non-invasive scalp gold plated disc electrodes (Grass–Telefactor Division, Astr – Med, Inc.), and a conductive gel after preparing the scalp with alcohol. Recording was done using ipsilateral ear as a reference electrode placement by a differential amplifier (Biopac Systems, Inc.). During recording, the gain was 2000; with the use of 100Hz low pass filter and 1.0 Hz high pass filter. EMG was recorded from right Adductor Pollicis muscle (APM) using Ag–AgCl surface disc electrodes (Swaromed Universal) with 3cm inter-electrode distance after careful scrubbing of the skin over the tested muscle with alcohol. The electrodes were placed in line with the muscle fibers direction. Each recording electrodes pair then connected by electrode cables to an amplifier (Biopac Systems, Inc.). The amplifier was set with a gain of 2000, low pass filter of 500 Hz, and high pass filter of 1.0 Hz Both amplifier contains a notch filter of 50dB, rejecting 50Hz noise.

A force transducer (BC 302, DS Europe s.r.l, Milan, Italy) was used to monitor the generated motor output of ADM during different stages of the experiment. Recording was performed through Acqknowledge 371 software (Biopac Systems, Inc.). EEG and EMG signals were digitized at 1000 Hz.

The subject was instructed about the experimental protocol and recording is performed inside a Faraday cage to reduce low frequency noise. Each subject was seated comfortably in a chair with both arms relaxed on a wooden board placed in front of him so that he/she can move his/her hand freely. EEG and EMG recording was performed simultaneously. After 25-45 seconds of recording while the subject was relaxed with his/her eyes closed, he/she has been asked by verbal command, which has been trained for it, to perform maximum voluntary contraction (MVC) of the right Adductor Pollicis muscle (APM) for 20 - 25 seconds (stage -1). After a relaxing period of 20 - 25 seconds the subject was asked to perform 50% of his/her MVC (stage - 2), while EEG/EMG recording was still performed simultaneously. A force transducer was used to monitor the generated MVC and to assess the 50% MVC.

The same experimental protocol has been repeated after APM fatigue (stage – 3, MVC after muscle fatigue, stage – 4, 50 % of MVC after muscle fatigue). Sustained MVC of APM for 60 seconds was used to induce fatigue of that muscle [15]. To ensure that the muscle was fatigued, in addition to the subject’s awareness of right APM fatigue, a decrease of 25% or more of the motor out-put, observed by changes in the force transducer channel, was regarded as a criterion to determine muscle fatigue.

**Data analysis**

EEG and EMG signals were inspected visually for any noise or movement artifacts. Ten seconds noise-free segments were used for analysis (simultaneous EMG signals of APM and contralateral motor cortex EEG signals). Using MATLAB 6.5, analysis program has been written to analyze the selected segment, which was divided into 120 partially overlapping windows of 500 samples duration.
Coherence was calculated based on the power spectra by the use of a fast Fourier transform (FFT) using the following function:

\[ K_{xy}(f) = \frac{|C_{xy}(f)|^2}{C_{xx}(f)C_{yy}(f)} \]

Where, \( C_{xx}(f) \), \( C_{yy}(f) \), and \( C_{xy}(f) \) are values of to- and cross spectra at a given frequency \( f \).

**Coherence significance estimation**

The level of coherence significance was estimated using Rosenberg et al equation \(^{18}\). In two independent signals, coherence above \( Z \) was considered significant at \( p < \alpha : Z = 1 - \alpha^{1/(n-1)} \)

Where “\( n \)” is the number of epochs used in the analysis. For 120 epochs used in coherence estimation, any value above “0.025” is considered significant (\( p<0.05 \)).

**Results**

Coherence function analysis was conducted between EEG signals recorded from left motor cortex and EMG from right APM.

The first set of data analyzed were that associated with MVC of right APM, and the second set of data were associated with 50% MVC of right APM.

Table-1 and Fig.-1 & 2 are showing the mean coherence values at each frequency between 2-50 Hz. for both sets of experiments respectively.

Maximum coherence value of (0.041) at 38 Hz. (in gamma band) was seen in non-fatigued MVC and a value of (0.042) at 32 Hz and 34 Hz. (in gamma band) for fatigued MVC of right APM. Another high coherence values were also observed in beta frequency band in both non-fatigued and fatigued contractions of right APM (0.039 at 20 Hz; and 0.038 at 20Hz. respectively).

Similarly, during 50% of MVC of right APM in non-fatigued contraction, maximum coherence value of (0.044) at 26 Hz (beta band) is noted; and another high coherence values are seen in alpha frequency band (0.043 at 10 Hz), and in gamma frequency band (0.031 at 42 Hz). In fatigued 50%MVC maximum coherence value is seen at beta frequency band (0.048 at 14 Hz) and another high value is seen at gamma frequency band (0.032 at 44Hz).
Table 1: EEG/EMG Coherence values (Mean) in nine subjects. MVC: maximum voluntary contraction, MVCfatig: MVC in fatigue, 50MVC: 50% of MVC, 50MVCfatig: 50% of MVC in fatigue.

<table>
<thead>
<tr>
<th>Freq.</th>
<th>MVC</th>
<th>MVCfatig</th>
<th>50MVC</th>
<th>50MVCfatig</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Hz</td>
<td>0.020</td>
<td>0.019</td>
<td>0.020</td>
<td>0.015</td>
</tr>
<tr>
<td>4Hz</td>
<td>0.017</td>
<td>0.018</td>
<td>0.015</td>
<td>0.021</td>
</tr>
<tr>
<td>6Hz</td>
<td>0.013</td>
<td>0.018</td>
<td>0.023</td>
<td>0.020</td>
</tr>
<tr>
<td>8Hz</td>
<td>0.020</td>
<td>0.020</td>
<td>0.028</td>
<td>0.014</td>
</tr>
<tr>
<td>10Hz</td>
<td>0.019</td>
<td>0.023</td>
<td>0.043</td>
<td>0.023</td>
</tr>
<tr>
<td>12Hz</td>
<td>0.021</td>
<td>0.018</td>
<td>0.020</td>
<td>0.010</td>
</tr>
<tr>
<td>14Hz</td>
<td>0.013</td>
<td>0.012</td>
<td>0.022</td>
<td>0.048</td>
</tr>
<tr>
<td>16Hz</td>
<td>0.028</td>
<td>0.022</td>
<td>0.012</td>
<td>0.035</td>
</tr>
<tr>
<td>18Hz</td>
<td>0.029</td>
<td>0.023</td>
<td>0.024</td>
<td>0.018</td>
</tr>
<tr>
<td>20Hz</td>
<td>0.039</td>
<td>0.038</td>
<td>0.017</td>
<td>0.018</td>
</tr>
<tr>
<td>22Hz</td>
<td>0.020</td>
<td>0.037</td>
<td>0.017</td>
<td>0.036</td>
</tr>
<tr>
<td>24Hz</td>
<td>0.024</td>
<td>0.019</td>
<td>0.012</td>
<td>0.011</td>
</tr>
<tr>
<td>26Hz</td>
<td>0.036</td>
<td>0.017</td>
<td>0.044</td>
<td>0.006</td>
</tr>
<tr>
<td>28Hz</td>
<td>0.013</td>
<td>0.036</td>
<td>0.020</td>
<td>0.009</td>
</tr>
<tr>
<td>30Hz</td>
<td>0.008</td>
<td>0.029</td>
<td>0.019</td>
<td>0.009</td>
</tr>
<tr>
<td>32Hz</td>
<td>0.024</td>
<td>0.042</td>
<td>0.027</td>
<td>0.020</td>
</tr>
<tr>
<td>34Hz</td>
<td>0.019</td>
<td>0.042</td>
<td>0.017</td>
<td>0.015</td>
</tr>
<tr>
<td>36Hz</td>
<td>0.037</td>
<td>0.016</td>
<td>0.021</td>
<td>0.022</td>
</tr>
<tr>
<td>38Hz</td>
<td>0.041</td>
<td>0.020</td>
<td>0.025</td>
<td>0.031</td>
</tr>
<tr>
<td>40Hz</td>
<td>0.040</td>
<td>0.030</td>
<td>0.019</td>
<td>0.018</td>
</tr>
<tr>
<td>42Hz</td>
<td>0.038</td>
<td>0.014</td>
<td>0.031</td>
<td>0.021</td>
</tr>
<tr>
<td>44Hz</td>
<td>0.036</td>
<td>0.021</td>
<td>0.022</td>
<td>0.032</td>
</tr>
<tr>
<td>46Hz</td>
<td>0.027</td>
<td>0.017</td>
<td>0.017</td>
<td>0.031</td>
</tr>
<tr>
<td>48Hz</td>
<td>0.012</td>
<td>0.009</td>
<td>0.019</td>
<td>0.016</td>
</tr>
<tr>
<td>50Hz</td>
<td>0.025</td>
<td>0.019</td>
<td>0.026</td>
<td>0.023</td>
</tr>
</tbody>
</table>

Discussion

Corticomuscular coherence value can be affected by the type of reference electrode used. EEG is measured against reference electrode (or electrodes), which should be electrically silent [9]. Different types of reference electrode methods were used in EEG recording: linked earlobe reference [16], common average reference [16], and the current source density estimation [17]. Significant corticomuscular coherence was observed in both linked earlobe and common average references EEG recording derivations [9] (which is the method used in this study).

Significant corticomuscular coherence was observed in both linked earlobe and common average references EEG recording derivations [9] (which is the method used in this study).

Pervious published works [4, 5, 6, 7] demonstrated that electrical cortical activity during sustained non-fatigued muscular contraction is coupled to synchronize motor units discharges reflected through the EMG signals.

In this study it has been shown that there is significant corticomuscular coherence during MVC of fatigued right APM. This result shows that the functional coupling between the motor cortex and the contracting muscle, demonstrated by significant EEG/EMG coherence, remains obvious during fatigued muscular contraction. The pattern of maximum coherence values seen in non-fatigued muscular contraction is also demonstrated in fatigued muscular contraction (In moderate contraction corticomuscular coherence is in beta frequency band; and in MVC it is in gamma frequency band).

In conclusion, these observations could demonstrate that the motor cortex and the contracting muscle preserve their functional coupling even in state of muscle fatigue during different levels of muscular contraction. This suggests physiological dependency of motor unit firing behaviors, of the contracting muscle, on the central motor cortical frequency-modulating mechanism. It looks reasonable to suggest that further studies in corticomuscular coherence estimation during muscle fatigue for different human muscles and during different tasks could support more the demonstrated observations of this study.
References