Power changes of EEG signals associated with muscle fatigue: The Root Mean Square analysis of EEG bands

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Abstract

This paper reports a research conducted to determine the changes in the electrical activity of the contralateral motor cortex of the brain that drives the maximum voluntary contraction (MVC) of right Adductor Pollicis muscle (APM) after fatigue. For this aim, the power changes of EEG signals after muscle fatigue were computed. EEG signals from the left motor cortical area (C3, FC3) in twenty-five subjects, simultaneously with the EMG from right Adductor Pollicis muscle (APM), before and after exercise-induced fatigue were recorded. The Root Mean Square (RMS) of the EEG bands (alpha, beta, and gamma) was calculated to determine the power changes of the EEG signals after right APM fatigue.

The mean RMS of EEG bands were increased during MVC of fatigued right APM compared to the RMS value during relaxation before fatigue ($p<0.05$). The RMS value was seen to be greatest in the beta band, and lowest in the gamma band. The observed increase in the RMS of EEG bands during MVC of fatigued right APM suggest an increase in the EEG signals power, which could reflect an increase in energy needed by the motor cortex to perform MVC in fatigued muscle, which might give an indication of neural fatigue in the motor cortex.

Keywords: EEG signals analysis; Central fatigue; Motor cortex; Maximum voluntary contraction.

1. Introduction

Muscle contraction with its resultant force generation results from a sequence of events starting in the motor cortex and ending in the contracting muscle. There are changes in all levels of motor pathway during and after fatigue contractions. The difficulty is to decide which changes are associated with fatigue and which actually contribute to the loss of muscle force [1].

Muscular fatigue can be reflected in a decrease of muscular performance and many investigators use this as a definition for fatigue. It has been defined as "inability to maintain the expected force or power output" [2]. Other investigators defined fatigue as "a loss of maximal force generating capacity" [3,4]. Fatigue can be divided into that occurring in the periphery and that which occurs in the central nervous system. Fatigue in the periphery (at the motor unit level) has been extensively investigated [5, 6, and 7].

It is known that muscle fatigue is associated with local and general metabolic changes. Clinically, cerebral metabolism is measured by studying cerebral circulation and/or oxygen in cerebral blood [8]. Pathological conditions affecting the metabolic process of the cerebrum (e.g. cerebral infection, severe cerebral vascular accident, hypoglycemic coma) are usually produce visually detectable abnormal EEG changes [9]. Recent studies [10, 11, 12, and 13] have determined the correlation between changes in cerebral metabolism, studied by positron emission tomography, with that seen in the EEG. From these studies, it could be concluded that the EEG record is a sensitive technique for determining changes in cerebral metabolism.

The EEG is used to investigate changes associated with central fatigue, but limited research has been done in the area of muscle fatigue using EEG [14]. The effects of muscle fatigue on Movement-Related Cortical Potentials (MRCPs) have been observed during fatiguing hand muscles contractions. MRCPs are cortical potential changes occurring before and after the execution of voluntary movements [15]. EEG data analysis has showed a significant increase in MRCPs amplitude derived from the motor cortex area associated with fatiguing muscular contractions, suggesting a possible link between the motor cortical signal and activity level of EMG during fatigue [14].

Another method that provides a measure of the strength of a biosignal is the root mean square (RMS) value [16,17]. The RMS is a statistical measure of the magnitude of a varying quantity. It can be calculated for a series of discrete values or for a continuously varying function. RMS is one of the most commonly used methods that measure the amplitude of a bio - signal, e.g. audiological signals and electromyographic signals. The amplitude of a bio-signal expresses the magnitude of the power (energy per time) of that particular signal (Basmajian et al., 1985; Cram et al., 1998). Measurement of RMS in different conditions affecting a biological system can give an index of the changes related to

that particular effect, e.g. the effect of fatigue on EMG signals.
The RMS for a collection of N values $\{x_1, x_2, \ldots, x_N\}$ is:

$$x_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \ldots + x_N^2}{N}}$$

The aim of this study is to determine the level of EEG signals power changes associated with maximum voluntary muscular contraction before and after peripheral muscle fatigue. The root mean square (RMS) of EEG amplitude is measured as an index of the power content of EEG recorded from the motor cortical area.

2.Methodology

A Subjects and Data acquisition:
Twenty-five right - handed normal volunteers, ten women and fifteen men, whose mean age was 35±12 years (SD), were studied. Potential participants were excluded if they had a history of any neurological, muscular or skeletal disease or disorder. Subjects were also excluded if they took any medication or substance that could affect motor performance. The experimental protocol was approved by the Ethics Committee of the Faculty of Engineering, RMIT University, and the subjects gave written informed consent for the experiment.

Using the International 10-20 electrodes placement system, EEG was recorded from the left motor cortical area (C3, FC3) using non-invasive scalp gold plated disc electrodes (Grass–Telefactor Division, Astr–Med, Inc.). The electrodes were covered with a conductive gel after preparing the scalp with alcohol, and then connected to Biopac recording amplifiers (Biopac Systems, Inc.). Recording was done using the ipsilateral ear as a reference electrode placement.

Simultaneous recording of the electromyography (EMG) of the right APM (along with the EEG recordings) was used to mark the events of muscular contraction and to determine the different periods of EEG associated with muscle contraction and relaxation. 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.

The biosignal recordings were performed inside a Faraday cage to reduce low frequency noise. The subject was seated comfortably in a chair with both arms relaxed on a wooden board placed in front of him so that free movement of the hands was possible. The subject was informed in particular to keep shoulder, neck and face muscles completely relaxed to eliminate any possible EMG induced artifact in the EEG records. EEG and EMG recordings were performed simultaneously for 25-45 seconds. Sustained MVC of APM for 60 seconds was used to induce fatigue of that muscle. This fatigue-inducing technique has been widely used since its first description by Merton [18]. After muscle fatigue, each subject was asked by an auditory cue to perform maximum voluntary contraction (MVC) of the right Adductor Pollicis muscle (APM) for 20 - 25 seconds. To ensure that the muscle was fatigued, in addition to the subject's self-awareness of right APM fatigue (the subject reported inability to sustain adduction of the thumb as strong as he/she could), 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.

B. Recoding System setting:
EEG was recorded using differential amplifier (Biopac, EEG100C). The gain was 2000, and output selection was on Normal. A 100Hz low pass filter and 1.0 Hz high pass filter were used to remove noise. The amplifier also contained a notch filter of 50dB rejecting 50Hz, and a common mode rejection ratio of 110dB min (50/60Hz). Input impedance was kept below 5 ohm.
EMG differential amplifier (Biopac, EMG100C) was set with gain of 2000; low pass filter of 500 Hz, and high pass filter of 1.0 Hz. The amplifier also contained a notch filter of 50dB rejecting 50Hz and a common mode rejection ratio of 110dB min (50/60Hz). Input impedance was kept below 5 ohm.
Recordings were performed through Acqknowledge 371 software (Biopac Systems, Inc.). Both EEG and EMG signals were digitized at 1000 Hz.

C. Computation of RMS:
Alpha [8-13 Hz], beta [13-30 Hz] and gamma [30-99 Hz] EEG bands RMS were computed using an algorithm written in MATLAB 6.5 program. The RMS values in time domain were calculated during relaxation (no contraction of right APM), and during MVC of fatigued right APM. The sum of the three EEG bands RMS is also computed to represent the total RMS of the analysed segment.
RMS was computed for each phase by taking 3 seconds segment from each recording stage. The visually selected EEG segment was chosen carefully so as to be noise and EMG artefact free.

3. Results

The RMS values of the EEG bands (alpha, beta and gamma) and the sum of the three bands RMS (at relaxation phase of right APM and during fatigued MVC of right APM in the 25 subjects) are seen in Figure-1 and 2. The mean RMS values of the 25 subjects are shown in Figure-3.

From Figure-3, during the relaxation phase, when the subject was not contracting the right APM, the mean RMSt value was 0.0427 ± 0.0104 (SD) mV. It increased to 0.0496 ± 0.0140 (SD) mV during MVC of fatigued right APM. Statistical significance was tested using the paired student t-test, which showed significant changes compared to relaxation phase value at $p < 0.05$.

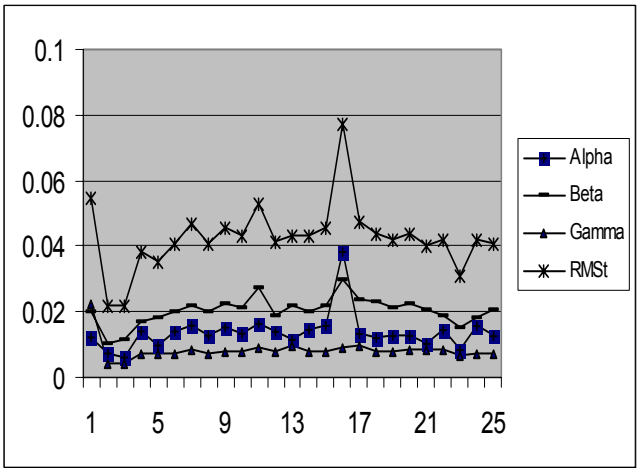

Figure-1, RMS values of EEG bands during Rt APM muscle relaxation. Alpha: alpha EEG band; beta: beta EEG band; gamma: gamma EEG band; RMSt: total RMS of 25 subjects.

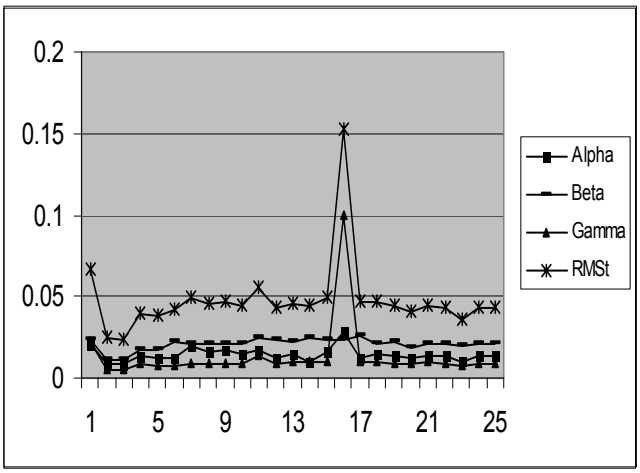

Figure-2, RMS values of EEG bands during fatigued relaxation of Rt. APM. Alpha: alpha EEG band; beta: beta EEG band; gamma: gamma EEG band; RMSt: total RMS of 25 subjects.

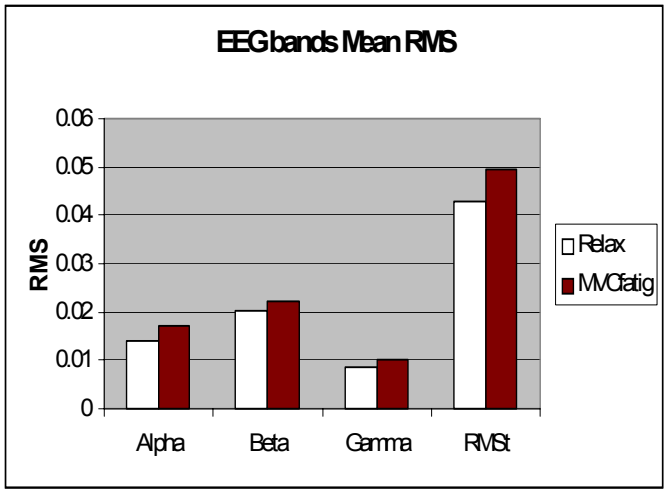

Figure-3, Mean RMS values of EEG bands. Alpha: alpha EEG band; beta: beta EEG band; gamma: gamma EEG band; RMSt: total RMS, Relax: relaxation phase of right APM, MVCfatig: fatigued MVC of right APM.

4. Discussion

The results showed obvious and significant increase in the EEG RMS values during MVC of fatigued right APM. This change is clearly due to peripheral muscle fatigue.
During right APM relaxation, the RMS values of the EEG bands and the sum of them were regarded as the base line readings of the EEG power (energy per time) recorded from the motor cortex. These values were significantly increased during MVC of fatigued right APM, which indicate an increase in EEG signals power of the left motor cortex. This could project the role of all the three EEG bands in the power changes of the EEG recorded from the left motor cortex associated with MVC of the right APM. The greatest change in RMS values was seen in Beta band, and the lowest was in gamma band. This pattern was constant during relaxation and MVC of fatigued right APM.

From the above, it is concluded that the power of EEG signals changes with peripheral muscle fatigue. This indicates the presence of a direct correlation between the motor cortex electrical activity and muscle fatigue.

If we consider that the electrical activity of the brain is reflecting the metabolic processes of the brain (Patel et al., 1997; Goldman et al., 2002; Laufs et al., 2003; Mattia et al., 2003), the change in EEG signals power is an index of a metabolic process in the motor cortex that aims to maintain the MVC after muscle fatigue.

To test this method of EEG signals analysis further, studies analyzing EEG signals associated with muscle fatigue of different muscles and/or during different movement tasks are recommended.

References

[1] Taylor, J. L., Gandevia, S.C. Transcranial Magnetic Stimulation and Human Muscle Fatigue. *Muscle Nerve* 24:18-29, 2001
[2] Edwards, R. H. T. Human muscle function and fatigue. *Ciba Found. Symp*.82: 1-18, 1981
[3] Bigland-Ritchie, B., Cafarelli, E. and Vollestand, N. K. Fatigue of submaximal static contraction. *Acta. Physiol. Scand*.128: 137-148, 1986
[4] Vollestad, N K; Sejersted, O M; Bahr, R; Wood, J J and Bigland-Ritchie, B "Motor drive and metabolic responses during repeated submaximal contraction in man". J Appl Physiol 64(4): 1421-1427, 1988
[5] Edwards, R.H D. T., Hill, D. K., Jones, D. A., Morton, P. A. Fatigue of long duration in human skeletal muscle after exercise. *J. Physiol.* 272:769-778, 1977.
[6] Bigland-Ritchie, B., Johansson, R., Lippold, O. C. J. and Woods, J. J. Contractile Speed and EMG changes during Fatigue of sustained Maximal Voluntary Contractions.*J. Neurophysiol.* 50:313-324, 1983.

[7] Kirya, T., Ushiyama, Y., Tanaka, K., Okada, M. Fatigue Assessment during Exercise using Myoelectric Signals and Heart rate Variability. *Proceeding of the 22nd Annual EMBS International Conference.* July 23-28 2000 Chicago IL.
[8] McCormick, P.W, Stewart, M., Goetting, M. G., Balakrishnan, G. Regional cerebrovascular oxygen saturation measured by optical spectroscopy in humans. *Stroke* 22:596-602, 1991.
[9] Aminoff, M .J. *Electrodiagnosis in clinical neurology*. 2nd. ed. NewYork: Churchill Livingstone, 1986.

[10] Patel, P., Al-Dayeh, L., Singh, M., Localization of alpha-activity by simultaneous fMRI and EEG measurements. *Proceedings of the International Society for Magnetic Resonance in Medicine.* 3: 1653, 1997.
[11] Goldman, R. T., Stern, J. M., Engel, J. Jr, Cohen, M.S. Simultaneous EEG and fMRI of the alpha rhythm. *NeuroReport* 13: 2487–2492, 2002.
[12] Laufs, H.., Kleinschmidt, A., Beyerle, A., Eger, E., Salek-Haddadi, A., Preibisch, C., Krakow, K. EEG-correlated fMRI of human alpha activity. *NeuroImage* 19: 1463-1476, 2003.
[13] Mattia, D., Babiloni, F., Romigi, A., Cincotti, F., Bianchi, L., Sperli, F., Placidi, F., Bozzao, A., Giacomini, P., Floris, R., Grazia Marciani, M. Quantitative EEG and dynamic susceptibility contrast MRI in Alzheimer's disease: a correlative study. *Clin. Neurophysiol.* 117: 1210-1216, 2003.
[14] Johnston, J., Rearick, M., Slobounov, S. Movement-related Cortical Potentials associated with progressive muscle fatigue in grasping task. *Clin. Neurophysiol*. 112: 68-77, 2001.
[15] Vaughan, H., G.,Jr; Costa, L.,D.and Ritter, W., "Topography of the human motor potential". Electroencephalogr Clin Neurophysiol 25: 1-10, 1968

[16] Basmajian, J. V., Deluca, J. C. *Muscles Alive. Their Functions Revealed by Electromyograph*. 5th ed. Baltimore, MD, USA: Williams & Wilkins, 1985.

[17] Cram, J. R., Kasman, G. S., Holtz, J. *Introduction to Surface Electromyography, Gaithersburg*. Maryland: Aspen Publishers, Inc. 1998.
[18] Merton, P. A. Voluntary strength and fatigue. *J. Physiol.* 123:553-564, 1954.