EEG Peak Alpha Frequency as an Indicator for Physical Fatigue

S.C. Ng[1], P. Raveendran[2]

[1]Department of Biomedical Engineering, University of Malaya, Kuala Lumpur, Malaysia
[2]Department of Biomedical Engineering, University of Malaya, Kuala Lumpur, Malaysia

Abstract— **The peak alpha frequency (PAF) has been associated with mental abilities. In this study, we use the EEG to investigate the relationship between PAF and physical fatigue. Eight right handed male subjects (age from 23 to 29) volunteered for the experiment. They have to perform a hand grip task for 30 seconds with each hand for 30 times or until they could not continue anymore. Electrodes are placed at 55 locations all over the scalp to detect EEG. Three electrodes are placed around the eyes region to detect EOG. The EEG signals of six subjects clearly indicated a reduction in the PAF around the motor cortex region after the physical exertion. Thus, this study shows that the reduction of PAF can be an indicator of physical fatigue.**

Keywords— **peak alpha frequency, muscle fatigue.**

I. Introduction

Lal and Craig, 2001 [1] did a comprehensive review on fatigue and specifically on driver's fatigue. Their review gave two definitions of fatigue which are: (a) reduced efficiency and a general unwillingness to work [2] and (b) disinclination to continue performing the task, and that it involved an impairment of human efficiency when work continued [3]. Murata et al. [4] relates fatigue to a loss of efficiency and disinclination to effort.

Gandevia [5] stated that fatigue could be separated into peripheral and central fatigue. Peripheral fatigue would refer to the reduction in the muscle ability and central fatigue refers to the central nervous system that fails to activate the motor neurons adequately. Review by Srinivasan [6] have defined peripheral fatigue as "the point at which the muscle is no longer able to sustain the required force or work output level [7]" while central fatigue as "the failure to sustain attentional tasks and physical activity as opposed to external stimulation, which exist in the absence of any clinically detectable motor weakness or dementia [8]".

Various studies on fatigue of different muscles have been carried out. Most studies of muscle fatigue are quantified using EMG. Studies have been carried out for fatigue due to different motions such as biking [6,9], soccer [10], computer game [11] and lifting [12] by recording and studying EMG activity. Root Mean Squared (RMS) of the EMG activities is commonly used to find the energy content of the EMG activity. A reduction in the RMS would indicate a reduction in the muscle ability to carry out the task and thus indicate fatigue. When a muscle is fatigued, lactic acid and carbon dioxide increase and the muscular tissue becomes acidic [2]. In the frequency domain, the peak frequency will shift to a lower value when fatigue sets in due to the lowering of pH in the muscle [13].

Recent works by Liu et al. [14-17] focused on the changes in the central nervous system due to fatigue. They have used fMRI [14] to study sustained maximal handgrip effort for 2 minutes. The fMRI revealed that brain activity increased substantially at first and then decreased due to fatigue. A later study by them [15] indicates that intermittent maximal voluntary contraction would reduce the power output at the muscle level (as indicated by EMG) but not the brain level (as indicated by the fMRI).

This research group later moves on from fMRI studies to EEG analysis of muscle fatigue. In 2005, Liu et al. [16] indicated that EEG signals in the alpha (8-14 Hz) and beta (14-35Hz) frequency band reduce in amplitude during maximal contraction when fatigue sets in. Liu et al. [17] showed that the activation center for the muscle activity shifted and grew in size due to fatigue. Thus, the brain requires more resources to activate the muscle when it is tired.

II. Peak alpha frequency

Earlier studies have shown that, peak alpha frequency (PAF) in the EEG increased from an infant to an adult and then started declining with age [18]. Marshall et al. [19] found the existence of the maximum relative power at the central region during toddlerhood and postulated that it may be indicative of intense development of locomotor ability. Stroganova et al. [20] found the PAF increased from 6.24 ± 0.45 Hz at 8 months to 6.78 ± 0.38 Hz at 11 months. Based on the sample of 550 subjects acquired from a total of 6 laboratories (2 laboratories from USA, Europe and Australia each), Clark et al. [21] found that PAF of adults reduced with age more prominently at the anterior compared to the posterior brain region. From the studies of Kopruner et al. [22], there seemed to be a linear relationship between age and PAF of adult subjects (PAF=11.95-0.053 x age).

Various studies have shown PAF related to response time [23] and memory performance [21,24,25]. Klimesch et al.

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[23] shows a higher PAF for subjects with faster response time. PAF of subjects with good memory is about 1 Hz higher than that of similar age subjects with bad memory [21,24,25]. Angelakis et al. [26] proposed PAF as an indicator for cognitive preparedness (the capacity of the brain to execute complex task). They found that subjects with traumatic brain injury having lower PAF than normal subjects during resting with eyes open after a working memory task.

Based on the review, physical fatigue would result in changes at the peripheral as well as the central level. A higher peak alpha frequency is indicative of a higher mental ability (Stated in Klimesch [25] and Angelakis et al. [26]). Studies by Liu et al. [16,17] indicate that muscle fatigue affects the EEG signals. In the present study, it is suggested that the peak alpha frequency, PAF would reduce when physical fatigues sets in.

III. Methodology

A. Subjects

Eight healthy right handed male subjects participated in the study (age: 23 to 30). The experimental protocol is first explained in detail to the subject. The subject is then required to fill in a consent form before the experiment begins.

The subject is seated comfortably on a chair. His arms are rested on his thighs. After the placement of electrodes, the subject is required to conduct two sessions of eyes closed for two minutes followed by eyes opened for another two minutes. After that, certain electrooculogram (EOG) artifacts are collected to perform the regression method to remove EOG artifacts for the experimental data. For the EOG artifacts, the subject is required to roll their eyes clockwise and counter clockwise. Then the subject has to look up, left, right and down. Finally, the subject is required to blink his eyes.

The actual experiment requires the subject to grip a Hand Grip device until the 2 ends touches or as much as possible if the subject is not strong enough to make the two ends touches. The subject will grip the hand grip using the right hand for 30 seconds. Then, he will wait for 5 seconds before changing it to the other hand. He will also state the level of effort that is involved to grip the device. Ten seconds later, he will grip the device with the other hand for 30 seconds. This set is repeated 30 times or until the subject could no longer grip the device anymore. Each hand will grip the device 30 times for 30 second each or until the subject could not continue anymore.

After the experiment, the subject is again required to conduct two sessions of eyes closed for two minutes followed by eyes opened for another two minutes. The eyes closed and eyes opened before and after the experiment will serve to indicate the changes in the brain state after the experiment.

B. Experimental Data Acquisition

EEG data were recorded from the scalp using the 64 channel GTec Electrocap. 55 channels of EEG signals according to the International 10-10 system was recorded (refer Fig. 1). The impedance at all the EEG electrodes are kept below 10 kΩ. Two electrodes are placed at the earlobe to enable Linked Ear referencing method. In order to remove the EOG artifacts according to the regression method suggested by Scholgl et al. [27], three electrodes are place around the eyes region (one at the forehead and the other two at the left and right cheekbone). Two pairs of Bipolar recording is also obtained EMG activities from the muscles at the left and right forearm.

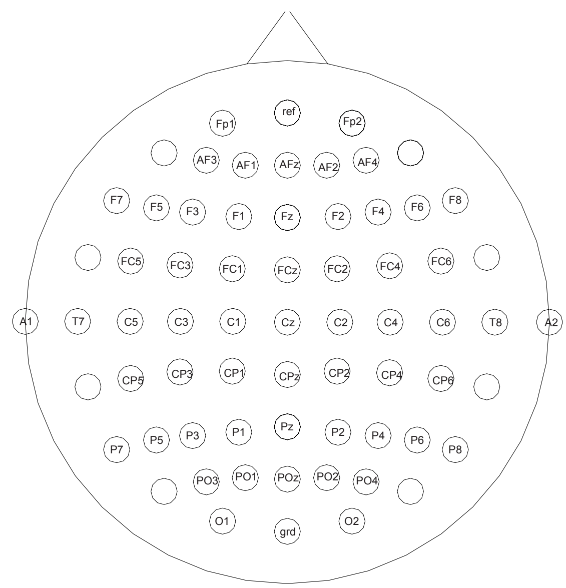

Fig. 1 Location for the placement of electrodes

IV. Signal processing

A. EOG Artifact Removal

Scholgl et al. [27] EOG removal method consists of 2 steps. The first step finds the regression coefficients for each EEG channel by applying equation (1) on to the EOG artifact induced signals. Once the regression coefficient is obtained, the EOG-artifact-removed EEG is obtained by applying equation (2) on to the raw EEG signals.

$$b = inv(EOG'*EOG)* (EOG'*EEG) \tag{1}$$

where,

b = regression coefficient for all the EEG channels
EOG = The 3 channels of EOG recording
EEG = The 55 channels of EEG recordings.

To obtain the artifact-removed EEG data, the formula (2) is used:

$$EEG_{new} = EEG-EOG*b \tag{2}$$

where,

EEG_{new} = EOG-artifact-removed EEG

B. Quantifying Peak Alpha Frequency

In his review of alpha and theta oscillations, Klimesch [25] proposed two methods to find the peak alpha frequency. The first method is to look for the distinct peak within the alpha frequency range. The second method finds the center of gravity within the alpha frequency range. He suggested using the center of gravity method particularly if there are multiple peaks in the alpha range. In 2005, Neuper et al. [28] tested both methods of finding peak alpha frequency and found that the center of gravity method gave more stable results. Thus, the center of gravity method of finding peak alpha frequency will be applied here.

In the current study, only the eyes closed data before and after the experiment will be processed. First, each of the eyes closed and eyes opened data that has been EOG removed is remontage using the Common Average Reference method. Then, it is segmented into 10-second intervals (to give frequency resolution of 0.1 Hz) with one second step size. Each ten second segment would be windowed using a Gaussian window to reduce spectral leakage. Then the signal is transformed into the frequency domain using Fourier Transform. The peak alpha frequency for that segment is determined using the center of gravity method assuming the range of 7-14 Hz as the alpha frequency band. The equation to find the peak alpha frequency is similar to the one used by Klimesch [25] and is given in equation (3)

$$PAF = \Sigma(a_f \times f)/ \Sigma a_f \tag{3}$$

where,

a_f = Amplitude of frequency f
f = Frequencies within the 7 to 14 Hz

The peak alpha frequency for each location will be determined individually. Then, for each segment of eyes closed data the mean for each individual location is found.

V. Results and discussion

In order to compare the effects of fatigue on to the peak alpha frequency (PAF), the PAF of each location before the experiment is subtracted from the corresponding location after the experiment.

From Fig. 2, it can be seen that the PAF at the motor cortex regions corresponding with the left and right hand have been reduced more significantly after the experiment as compared to the other region of the brain. This may be an indication that the mental control over the left and right hand have been reduced due to fatigue.

Based on Table 1, six out of the eight subjects have distinctive reduction of PAF around the motor cortex region (similar to the topographical plot of Fig. 2). Two subjects (S4 and S7) have no change in the PAF. It is interesting to note that these two subjects skipped their lunch before the experiment.

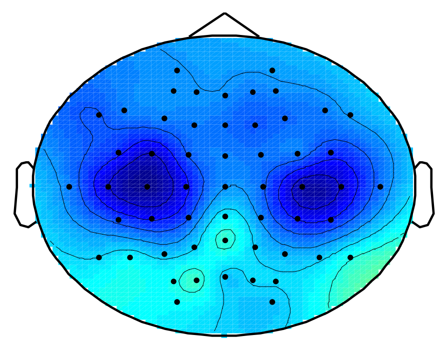

Fig. 2 Differences of PAF before and after experiment.

Table 1 The peak alpha frequency before and after experiment

		Left Region			Right Region	
		Before	After		Before	After
S1	FC3	9.3(0.4)	9.0(0.3)	FC4	9.4(0.4	9.1(0.2)
S2	CP3	10.0(0.2)	9.6(0.3)	CP4	10.1(0.2)	9.6(0.2)
S3	C5	10.9(0.3)	10.4(0.2)	FC6	11.5(0.5)	10.3(0.3)
S4	CP3	10.0(0.3)	10.0(0.2)	CP4	10.0(0.2	9.9(0.2)
S5	C3	10.6(0.4)	10.2(0.3)	C4	10.6(0.4)	10.1(0.2)
S6	C3	10.5(0.3)	10.1(0.2)	C4	10.5(0.3)	10.0(0.2)
S7	CP3	10.4(0.2)	10.4(0.3)	C4	10.0(0.3)	10.0(0.4)
S8	FC3	10.8(0.5)	10.4(0.2)	FC4	10.7(0.5)	10.1(0.3)
Mean		10.3	10.0		10.4	9.9

The standard deviation is given in brackets

It can also be seen that the most reactive location to fatigue is located around the motor cortex region. It is usually at the C3 (or C4) location or their adjacent location (which is the motor cortex region for the control of hand). For the subjects that indicate a reduction in the PAF, the frequency reduction is around 0.4 Hz at the left brain region while it is about 0.6 Hz at the right brain region. This may be indicating that the same load perform by both hands resulted in a higher fatigue level at the left hand (contralateral to the right region) since all the subjects are right handed.

VI. Conclusion

In this experimental study, eight subjects were subjected to hand grip task for 30 seconds with each hand for 30 times or until they could not continue anymore. The study found six of the subjects' peak alpha frequency reduced. Two of the subjects skipped their lunch and quit after a few trials, which were not sufficient enough to indicate any change in PAF. The PAF reduction is most prominent at the motor cortex region associated with hand control.

Acknowledgment

Format the Acknowledgment and References headlines without numbering.

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Author: Ng Siew Cheok
Institute: University of Malaya
City: Kuala Lumpur
Country: Malaysia
Email: siewcng@um.edu.my