

Discrimination of Brain States Using Wavelet and Power Spectral Density

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Abstract. Cognitive task produces activation in the brain which are different from normal state. In order to study the brain behavior during cognitive state, different techniques are available. Wavelet energy and power spectral density (PSD) are well established methods for brain signal classification. In this paper, cognitive state of the brain is compared with the baseline using EEG. Data are taken from all lobes of the brain to see the effect of cognitive task in the whole brain and analyzed using wavelet energy and PSD. Graph of wavelet energy and power spectral density are plotted separately for each subject to see the effect individually. Individual results showed that the behavior of human brain change with the cognitive task and this change occurred in most of the human brain. This change is due to the neural activity which is increased during the cognitive task (IQ) and is better measured with wavelet compared to PSD.

Keywords: Electroencephalography (EEG) · Wavelet energy · Power spectral density

1 Introduction

The physiology of human cognition can be studied using different noninvasive techniques like Electroencephalography (EEG), Magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI).

From last few decades, EEG is commonly used technique to measure brain activities. fMRI is well established technique and gives good result but is expensive compared to EEG [1]. In EEG, electrical potentials on the scalp are measured which tells about the electrical activity of the brain tissue. EEG can differentiate the mental activities and cognitive states, which help in better understanding of brain functions. This is one of the reasons that EEG is particularly used for clinic diagnostics and Brain Computer Interface (BCI).

EEG is one of the main methods for brain studies but it is not easy to measure brain activities using EEG because EEG has some limitations like artifacts and quality of signals. These limitations have been overcome in many studies. It is widely used due to

its advantages like convenience and cost but the main cause of success is that the subjects are free to move around due to wireless EEG setup available now a days.

The human brain has billions of neurons which are responsible for different types of activities. EEG signal can be classified into different frequency bands, alpha (α), beta (β), gamma (γ), delta (δ) and theta (θ) bands. In brain, whenever there is a neural activity, there are activations in different brain regions. Different parts of brain are inter-connected and different brain regions are activated during single task. For example during a cognitive task, there is change in neural activity in the whole brain i.e. occipital, frontal, parietal and temporal.

The brain activity may varies for different participants due to some reasons like IQ level, age, attention and level of difficulty of the task. In different studies these factors are discussed. In a study [2] H.S. Locke and T.S. Braver defined that cognitive behavior during a task is dependent on the level of motivation. Similarly, some studies showed that cognitive behavior is also dependent on memory [3, 4].

In a study, L. J. Trejo et al. [5] measured EEG for mental arithmetic task. In this study, statistical model was created by using data from frontal and parietal regions.

P300 was also found for the cognitive tasks and showed that amplitude is high in high workload tasks [6]. It is also showed that due to long periods of wakefulness, the amplitude of P300 decreases [7]. Normally, participants who are strong in cognitive tasks are intelligent and smart [8].

Due to all these factors, we took young university students as subjects for this study and presented our results individually for every participant. EEG recording during eyes closed (EC) has been used for the baseline. There were differences in peak values among the subjects but the cognitive behavior of all participants is significantly different from the baseline (for details please see the result section).

In this paper, we discriminate between brain states during cognitive task and the baseline (EC) by using different techniques i.e. energy and power. We took eight subjects and the data was taken from 17 different channels which are from every part of the brain. These channels are from occipital, frontal, temporal and parietal. In previous studies, estimation of cognitive states have been done but with limited number of channels [9, 10]. The analysis is done by using two different techniques, i.e. Wavelet energy and power spectral density (PSD). The result shows that wavelet energy gives better results than PSD.

2 Energy and Power

The EEG signal has different spectral components. The magnitude of EEG signal taken from human brain is in the range of 10 to 100 μV and the important frequencies are in the range of 0 to 30 Hz. In this study, we have found the energy of EEG signal by using wavelet transform. Wavelets are best for non-stationary signal analysis as it decomposes the signal into bunch of signals. Wavelet transform gives us better information and localization about time and frequency. In this study, we used continuous wavelet transform (CWT).

The mathematical equation for CWT is described as

$$W(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \cdot \psi^* \left(\frac{t-b}{a} \right) dt \quad (1)$$

where $W(a, b)$ is the CWT of function $x(t)$ and $\psi(t)$ is a continuous function in both the time domain and the frequency domain called the mother wavelet, while the $*$ represents operation of complex conjugate. The main purpose of the mother wavelet is to provide a source function to generate the daughter wavelets which are simply the translated and scaled versions of the mother wavelet. We call it CWT because the parameter b and a are in continuous domain, where b is known as translation (shifting), a is known as dilation (scaling) and $*$ represents operation of complex conjugate. The mother wavelet, also called the wavelet function, is the basic wavelet and all subsequent analysis is performed by using the shifted and scaled version of mother wavelet. In this study, we have used symlet as a mother wavelet.

The power spectral density (PSD) is a well-established method for EEG data analysis. It is used as a feature for signal classification to find power for EEG signals [11]. Different brain states can be distinguished by having different power in different frequency range. It shows the strength (power) of energy at different frequencies i.e. we can find that on which frequencies the energy is strong. It is also easily measurable and observable. In this study, the PSD is found using Welch method with 50 % overlapping. PSD is used for the continuous signal and the integral of PSD computes the average power within the signal over a given frequency band. The mathematical equation for PSD is as follows

$$P = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T x^2(t) dt \quad (2)$$

PSD is the frequency response of a random or periodic signal and the above equation tells where the average power is distributed as a function of frequency. P is the PSD of the signal $x(t)$ which is integrated over a large time interval $[-T, T]$.

3 Materials and Methods

3.1 Preprocessing

The raw EEG data had been filtered at 1–48 Hz frequency by using band pass filter and waveform tools is used to detect the artifacts. This waveform tool is available within net station software (EGI Inc). The detected artifacts were removed using regression based model [12] using electrooculography (EOG) channels (EOG channel more than 140 μ V).

3.2 Participants

In this experiment there were 8 subjects. All subjects were volunteers and their ages were between 20–30 years. The subjects were healthy with normal vision. The age of subjects was in between 20 to 30. All subjects filled the consent form and the study was approved by the research ethics committee of Universiti Teknologi PETRONAS (UTP).

3.3 Tasks

This experiment involved 2 physiological conditions: eyes closed and cognitive task. In the task, 40 different multiple choice questions were presented to the subjects. The set of questions consists of both mathematical and figurative questions. The subject can choose only one option within given time. The given time of each question is 60 s. After the response, the subject was exposed to the next question immediately without waiting. In the beginning, questions were easy as compared to the later ones.

3.4 EEG Recording Procedure

Data were recorded using 128 channel Electrical Geodesics Incorporated (EGI) system. All recordings were performed at Centre of Intelligent Signal and Imaging Research, University Technology PETRONAS (UTP). Task details are given above and for the baseline readings; data was taken with eyes closed.

4 Results and Discussion

EEG data was measured from 8 subjects in two conditions i.e. cognitive (IQ) task and eyes closed (baseline). Data are taken from every part of the brain for analysis. We have taken channel 70, 75, 83, 90 and 65 from occipital region, 96, 58, 45 and 108 from temporal, 62, 92 and 52 from parietal, 11, 24, 33, 124 and 122 from frontal. A total of 17 channels were selected from the whole brain. All channels show significant difference during cognitive task which shows that neural activity is increased in every part of the brain. The peak is in frontal and temporal region which shows more neural activity during cognitive task in these regions.

The result of all eight participants is shown individually. In Fig. 1(a–h), the wavelet energy of every subject is shown individually. Sub1 means subject 1. In every figure, we can clearly see the difference between both states at each channel.

In x-axis we are representing the channels and y-axis describes the wavelet energy. The first channel is 70 from occipital and the last is 122 from frontal. Red line shows the wavelet energy during IQ task and the blue line shows the wavelet energy during baseline which is eyes closed. In all the graphs, the neural activity is high during the task compared to baseline. In some regions, it is higher than other like in frontal and temporal. The wavelet energy is increased with the cognitive task compared to baseline

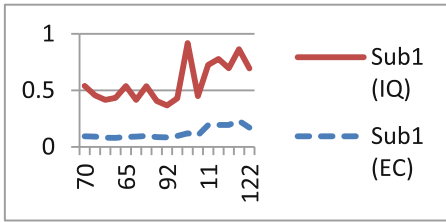


Fig: 1 (a)

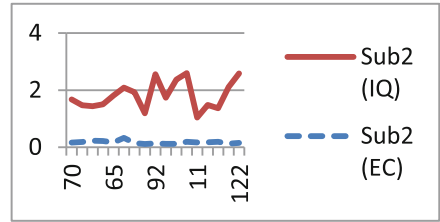


Fig: 1 (b)

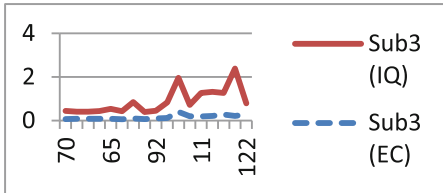


Fig: 1 (c)

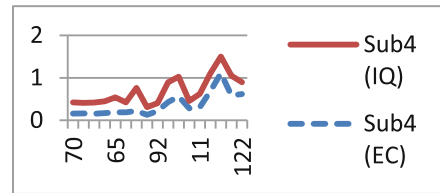


Fig: 1 (d)

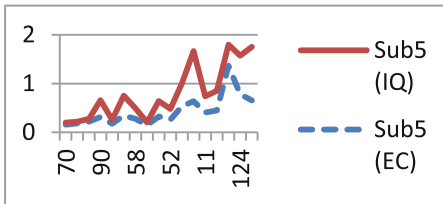


Fig: 1 (e)

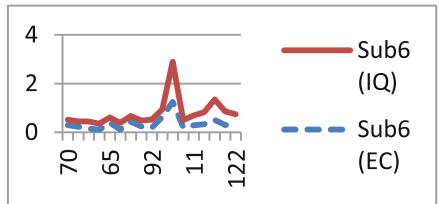


Fig: 1 (f)

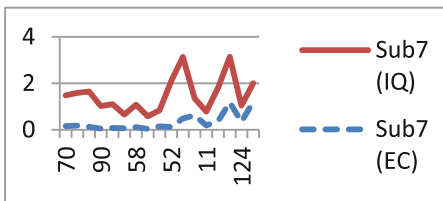


Fig: 1 (g)

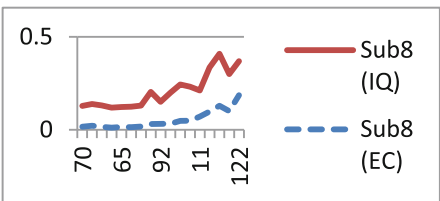


Fig: 1 (h)

Fig. 1. (a–h) shows the wavelet energy of eight different subjects (1–8) respectively.

especially in channels 45 and 124. If we see first subject’s data, from the first channel i.e. 70 till the end i.e. 122, a clear difference between both the states i.e. IQ and EC is seen.

We also found the difference between two states using power spectral density. Figure 2(a–h) shows the acceptable difference for all the eight subjects. Although, it is not as clear as in case of wavelets but it is enough to discriminate two states. During EC, the alpha frequency is dominant and alpha has a large magnitude so in PSD we did not have a clear difference between the two states.

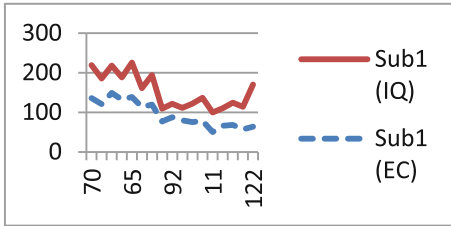


Fig: 2 (a)

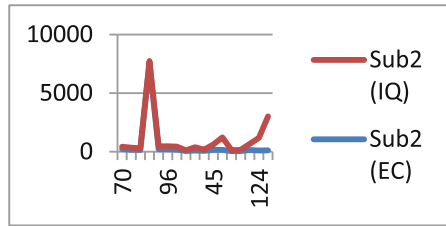


Fig: 2 (b)

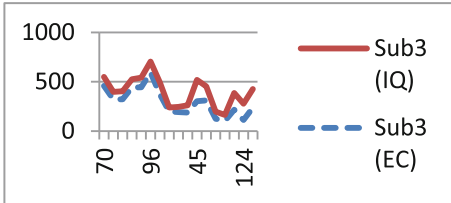


Fig: 2 (c)

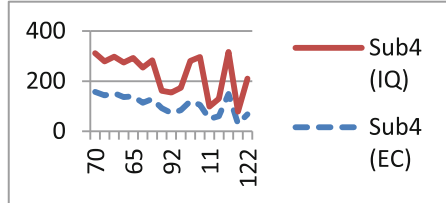


Fig: 2 (d)

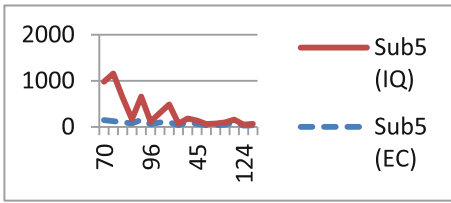


Fig: 2 (e)

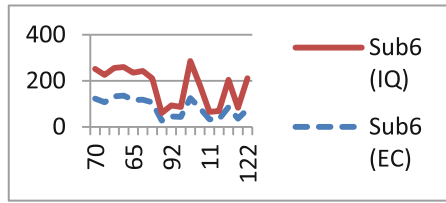


Fig: 2 (f)

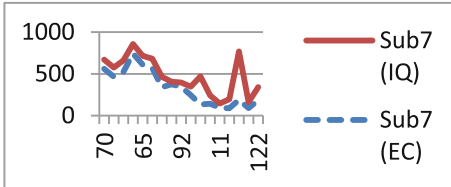


Fig: 2 (g)

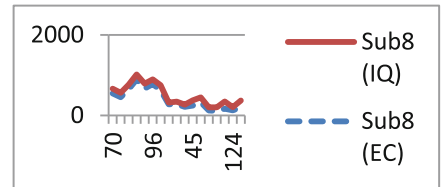


Fig: 2 (h)

Fig. 2. (a–h) shows the power spectral density of eight different subjects (1–8) respectively.

If we summarize the results quantitatively then it can be said that the increase in wavelet energy during IQ is more than 100 % compared to baseline in most of the channels. So the difference between brain states can easily be measured. In case of PSD, the difference between IQ and EC is much lesser and in most of the cases it is less than 10 %.

5 Conclusion

Brain states can be measured using EEG but it requires good statistical analysis so better technique should be used to get significant information. Significant difference in brain states i.e. IQ task and relaxed state (EC) are found using wavelet and PSD. The

result showed that wavelet energy gives better results compared to PSD. This is because in wavelet, the information is both in time and frequency domain. In results, higher wavelet energy was found during the cognitive task which showed that neural activity is increased during the cognitive task especially in frontal and temporal region. Power spectral density is also increased with cognitive task and gave acceptable results with the baseline.

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