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Cross coherence independent component analysis in resting and action states EEG discrimination

A Almurshedi and A K Ismail

Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor, Malaysia

E-mail: khamim@utm.my

Abstract Cross Coherence time frequency transform and independent component analysis (ICA) method were used to analyse the electroencephalogram (EEG) signals in resting and action states during open and close eyes conditions. From the topographical scalp distributions of delta, theta, alpha, and beta power spectrum can clearly discriminate between the signal when the eyes were open or closed, but it was difficult to distinguish between resting and action states when the eyes were closed. In open eyes condition, the frontal area (Fp1, Fp2) was activated (higher power) in delta and theta bands whilst occipital (O1, O2) and partial (P3, P4, Pz) area of brain was activated alpha band in closed eyes condition. The cross coherence method of time frequency analysis is capable of discrimination between rest and action brain signals in closed eyes condition.

1. Introduction

There are many differences in EEG signals between open and close eyes conditions. In different studies, different methods, such as power spectral analysis of EEG signals in open and closed eyes [1] and alpha activity in occipital lobe, are employed to analyse EEG signals. A study in 2007 [2] used Fourier transform to analyse EEG signals in open and closed eyes states, this study reported that the topographic changes were evident in all bands except for alpha band, and confirmed the use of mean alpha level as a measure of resting state arousal under open and closed eyes conditions. In a 2009 study, [3] researchers studied arousal vs. activation in children, their results confirmed the use of mean alpha level as a measure of resting state arousal under closed and open eyes conditions. Focal changes in the other bands reflect differences in activation; rather than the simple increase in arousal presented by alpha. Other techniques commonly utilized for EEG signals analysis include Fast Fourier transform, wavelet transformation dyadic filter bank, principal component analysis (PCA) and independent component analysis (ICA) [4, 5].

ICA has been used for EEG analysis in recent years [4]. It has been proven to be effective in removing the artifact from EEG signal [6]. Blink artifact is one of the very common noises in EEG signal. Cross Coherence is a statistical method that measures the degree of relationship, as a function of frequency, between two time series [7]. EEGLAB Matlab toolbox [8] is used to process the data and calculate ICA and cross coherence after discuss Brain Electrical Activity Mapping (BEAM) and power spectral analysis for two conditions open and close eyes in the resting and action states.

In this work, the traditional techniques Brain Electrical Activity Mapping (BEAM) were discussed. it can easily separate between open and closed eyes conditions, but cannot differentiate between resting and action states in closed eyes condition. For this purpose, ICA and cross coherence methods were used to study the relationship between the channels and components. The analysis of resting and action state of brain is very important to understand the behaviour of normal brain. Such study is helpful in monitoring of cognitive brain process including thinking, imagination, task difficulty and decision making and diagnosis of different brain diseases such as Depression, Migraine, Sleep Disorders, Learning Disabilities, Epilepsy and ADHD. This study provides evidences to the significance of ICA for removing the noise and cross coherence method for distinguishing between rest and action states of the brain in closed eyes condition.

2. Method and experiment

2.1. Participants

Twelve young students, all from Department of Physics in UTM, participated in this experiment. Their mean age was 25 (range 22–31) years old and all were right handed. Subjects were screened for neurological and physiological disorders, and no head injury. Some of them were wearing corrected sight vision lens during the experiment. The participants were voluntary and their written assent was obtained. They were informed about the protocol and the aim of this study. They were instructed to sit comfortably and to reduce the movement and blinking as possible; however they are asked to keep themselves attentive during the experiment. The experiment was conducted in the Instrumentation 4 Lab, the Department of Physics, Universiti Teknologi Malaysia.

2.2. EEG measurements

EEG data collected from 19-channel commercial KT88-2400 system (Digital EEG Topography). The impedance of each electrode was matched with the help of an LED indicator. Electrodes positions were distributed using 10-20 electrode system as suggested by [9]. The right and left hemispheres were referenced to the right and left earlobes (A1, A2) respectively and grounded to the forehead (A). The data was digitized at 200 Hz sampling frequency, and filtered using bandpass filter with 1-35 Hz frequency band. The routine continuous EEG data was recorded for each 3 min in two conditions, when the eyes are opened and closed, and in two states during resting and action state. The recorded data was saved on the hard disc for further offline processing. For each subject in each condition, the data is recorded from 19 electrode (Fp1, Fp2, F3, F4, F7, F8, Fz, T3, T4, C3, C4, Cz, T5, T6, P3, P4, Pz, O1, O2), power spectra were calculated using Fast Fourier Transforms. At each electrode, absolute power in the delta (0.8–3.8 Hz), theta (4–7.8 Hz), alpha (8–12.8 Hz) and beta (13–30 Hz) bands were calculated. ICA was performed using EEGLab Matlab toolbox after inserting of channel location. Furthermore, the time frequency analysis was applied to calculate cross coherence between active channels and components.

3. Independent component analysis

Independent Component Analysis is a method of decomposing a set of multivariate data into its underlying statistically independent components. Aapo Hyvärinen [10] rigorously defined ICA using the statistical latent variables model. Under this model, there is n random variables $X_1, X_2, \dots, X_n$ which are linear combinations of n random latent variables $S_1, S_2, \dots, S_n$, as in equation (1). The latent variables are the sources S_i, which are statistically independent. They are called latent because they cannot directly be observed. They are also called as "independent components".

$$X = a_{\,1}S_1 + a_{\,2}S_2 + \dots + a_{in}S_n \tag{1}$$

Both the independent components S_i and the mixing coefficients a_{ij} are unknown and must be estimated using the observed data X_i. The ICA latent variables model is better represented in matrix form [11]. If, $S = [S_1, S_2, S_3, \dots, S_n]^T$ represents the original multivariate data that is transformed through some transformation matrix H producing X, as in equation (2), then ICA tries to identify an unmixing matrix W, as described in equation (3).

$$X = H\,S \tag{2}$$
$$W \approx H^{-1} \tag{3}$$

So, that the resulting matrix Y is:

$$Y = WX = W(HS) = S' \approx S \tag{4}$$

ICA demands that the original signals $S_1, S_2, \ldots S_n$, be at any time instant, statistically independent and the mixing of the sources be linear. In case of EEG signals, m-scalp electrodes picking up correlated signals from brain. EEG is a multivariate data interfered with muscle artifacts, such as eye blinks and head movements. Assuming that EEG data can be modelled as a collection of statistically independent brain signals [11].

4. Cross coherence

The amount of phase stability between two different time series can be measured, which is called coherence. Coherence combines the phase angle between two signals. Coherence is either one, when the phase difference between signals is constant, or zero, when the phase difference between signals is random. In certain cases, a constant phase angle difference appears between two different frequencies. This is termed as cross-frequency coherence or bi-spectral coherence [12, 13]. If the measures are within the same frequency band, then the terminology is basically coherence which assumes auto-frequency coherence. Coherence is a statistic of phase differences and yields a much finer measure of shared energy between mixtures of periodic signals. In fact, coherence is essential because the degree of relationship or coupling between any two living systems cannot be fully understood without the knowledge of its frequency structure over a relatively long period of time.

5. Result and Discussion

From the power spectrum in both states (i.e. resting and action), it has been noticed that the power spectrum was higher in the electrode position O1,O2, P3,P4, Pz. Based on BEAM, it is very difficult to differentiate between these two states since they are very close to each other in their frequency spectrum.

Table 1. Power spectrum from electrodes distribution of open, close, resting and action states.

Electrode Position	Open Eye (μv^2/Hz)	Close Eyes (μv^2/Hz)	
		Resting	Action
Fp1	65.7	7.3	9.0
Fp2	95.9	7.2	8.8
O1	10.6	51.0	53.1
O2	3.6	47.3	42.6
P3	14.0	46.0	42.7
P4	18.4	50.7	51.4
Pz	17.5	50.9	50.4

The power spectrum of seven selected electrodes (Fp1, Fp2, O1, O2, P3, P4, Pz) are shown in Table 1. These positions were selected due to its variances, as it shows the differences in the power frequency during open and close eyes. In open eyes condition, the highest power was at the frontal lobe (Fp1, Fp2) (95.9), but when the eyes were closed the power was relatively smaller, it was distributed between occipital (O1, O2) and parietal (P3, P4, Pz) the maximum was at occipital lobe (53.1) and these show good agreement with [14]. The activation of the brain lobe is based on the maximum frequency spectrum available at a specific electrode position.

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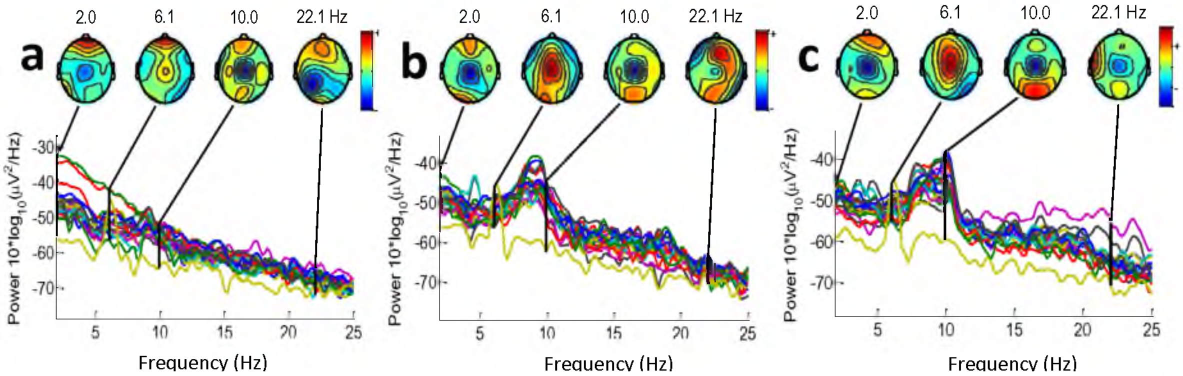
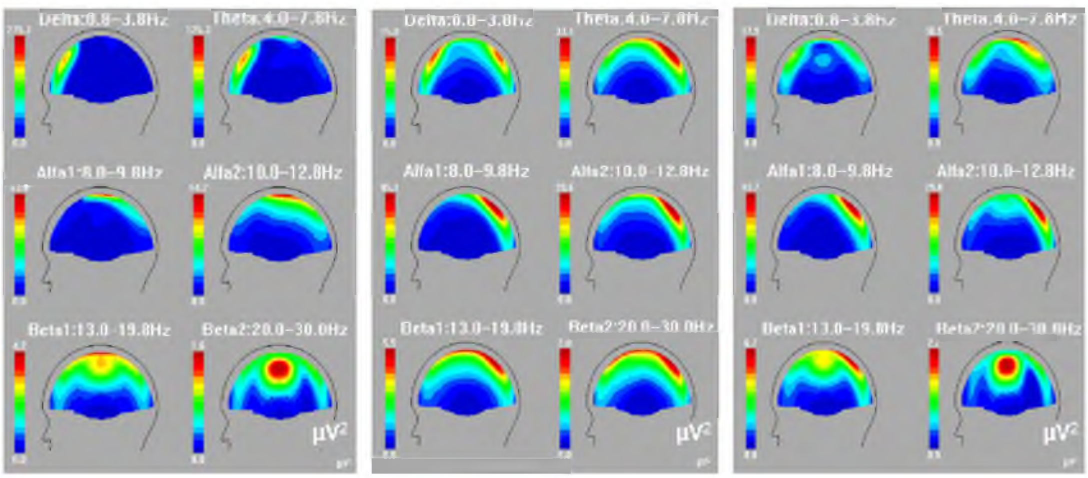


Figure 1. Channel power spectrum and topographical maps a) open eyes b) resting state c) action state.

The spectra of all electrodes, for open and close eyes conditions are presented in Figure 1. Clear differences can be observed between the spectra of open eyes (Figure 1a), close eyes rest state (Figure 1b) and close eyes action state (Figure 1c). As can be seen from Figure 1 (a), the frontal lobe is active with a higher power at low frequency and reduces gradually as the frequency increase. In Figure 1 (b,c), the higher power is moved to parietal and occipital lobes, while the prominent peak remained around 10 Hz. Comparing two conditions (open and close eyes), the power of delta, theta and alpha were intense in both conditions.

The topographical distributions of power and frequency bands are shown in Figure 2. The left columns (Figure 2a) present activity theta, delta, alpha and beta for open eyes condition. The middle columns (Figure 2b) depict brain activity in the resting state for close eyes condition, while the right set of columns (Figure 2c) shows the brain activity of action stat. In Figure 2, big differences for open eyes condition where the theta and delta power is much greater than for close eyes condition whereas the early alpha power is greater for the close eyes condition. The difference is almost double in both conditions. This result supported that Parieto-Occipital alpha waves during periods of eyes closed are the strongest EEG brain signals [15]. There was no noticeable marked difference in beta band. Based on Figure 2 it is very clear to distinguish between open and close eyes conditions. Since in open eyes condition, the frontal area is active with a high power of delta and theta bands whereas in close eyes conditions for both states, resting and action, alpha wave is active in partial-occipital area. These results are very similar to the open vs. closed eyes differences previously published [2].



a **b** **c**

Figure 2. Brain electrical activity mapping (BEAM) for open eyes (a), close eyes resting state (b) and close eyes action state (c).

BEAM shows the topographical distribution and power spectrum frequency difference between open and close eyes. It also shows the activity of occipital and parietal lobes of brain in both resting and action states, but cannot easily differentiate between action and resting state of brain. For this reason, we tried to apply independent component analysis (ICA) and cross coherence between active channels and components.

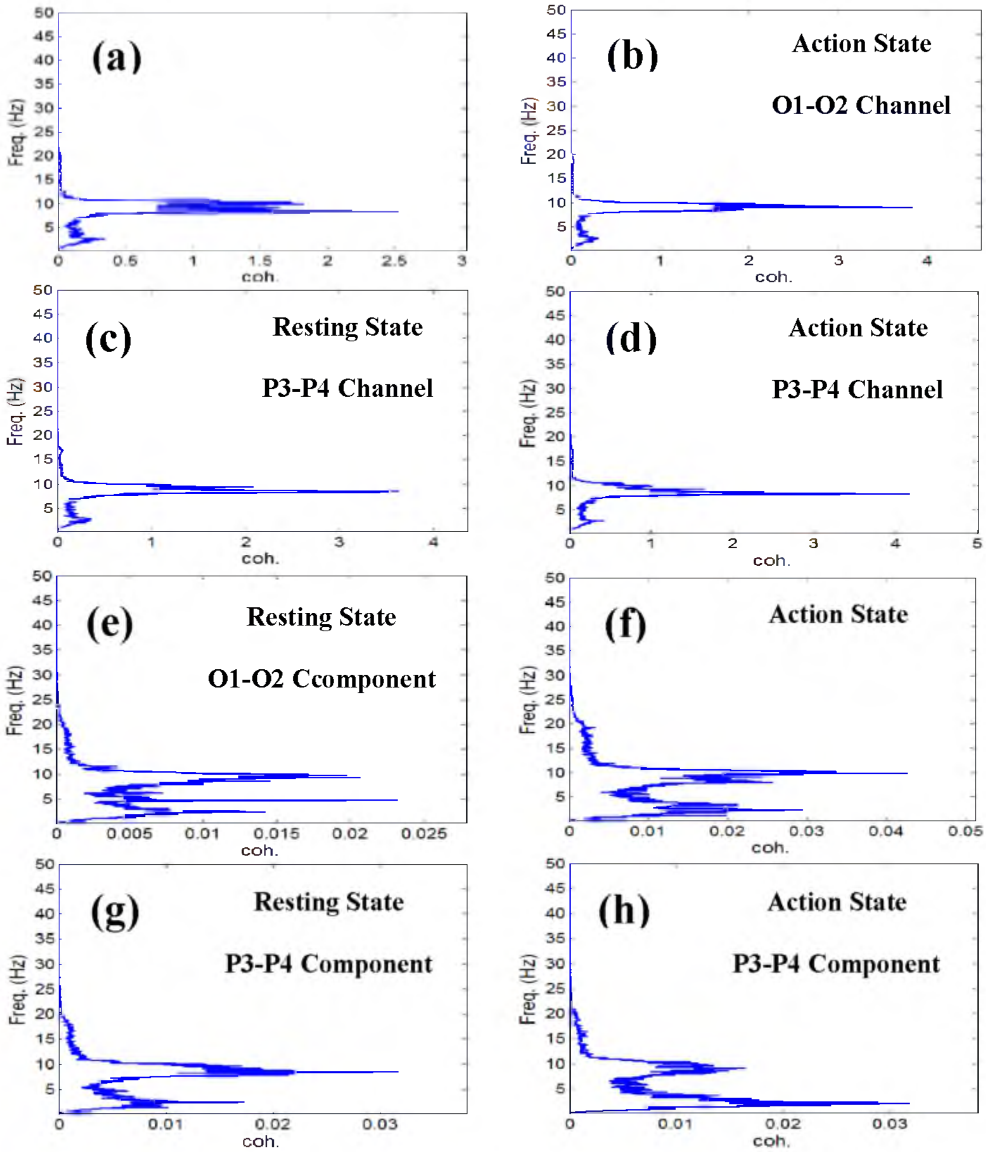


Figure 3. Cross coherence between channels and components right for resting state and left for the action state.

Figure 3 shows the result of cross coherence between EEG channels and components. In Figure 3, the cross coherence between channels and components plotted vs. frequency. The left column (Figure 3 a, c, e & g) for the resting state and the right column (Figure 3 b, d, f & h) for the action state. The first four graphs in Figure 3 are channel cross coherence between (O1-O2) and (P3-P4) in Figure (3a, 3b) and Figure (3c, 3d) respectively. Whereas the last four graphs show the component cross coherence of (O1-O2) and (P3-P4) in Figure (3e, 3f) and Figure (3g, 3h) respectively. The cross coherence between the channels observed with a sharp clear peak around 10 Hz. After applying ICA, the cross coherence between the components cover slower frequency area reaching 10 Hz, this happened because ICA removed the blink artifact and noise from the signals [6]. From Figure 3, there is more cross coherence between channels and components in action state than in resting state. This result indicates that there is more coherence between right and left hemisphere in action stare of brain than that in the resting state.

6. Conclusion

In this paper, the power spectrum brain topography was applied to analyse and distinguish EEG signal between close and open eyes conditions. Results confirmed the difference of power activation since delta and theta frequency band in the frontal brain lobe were active in the open eyes condition and early alpha wave in the parietal occipital brain lobe was active in close eyes condition. The ability and weakness of this method were discussed to differentiate between the resting and action states for close eyes condition. A method of using independent component analysis (ICA) and cross coherence time-frequency analysis was proposed to show the difference between these states. The proposed method show that the cross coherence between channels and components is always greater in the active state than resting state, i.e. there is stronger relation between both hemispheres in action state than that in the resting state. These results present the relationship between the channels and components and also show a great finding of power disruption in the brain for different conditions and states. The cross coherence method succeeds to distinguish between action and resting state of brain.

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