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Independent Component Analysis of EEG Dipole Source Localization in Resting and Action State of Brain

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Abstract. EEG source localization was studied in order to determine the location of the brain sources that are responsible for the measured potentials at the scalp electrodes using EEGLAB with Independent Component Analysis (ICA) algorithm. Neuron source locations are responsible in generating current dipoles in different states of brain through the measured potentials. The current dipole sources localization are measured by fitting an equivalent current dipole model using a non-linear optimization technique with the implementation of standardized boundary element head model. To fit dipole models to ICA components in an EEGLAB dataset, ICA decomposition is performed and appropriate components to be fitted are selected. The topographical scalp distributions of delta, theta, alpha, and beta power spectrum and cross coherence of EEG signals are observed. In close eyes condition it shows that during resting and action states of brain, alpha band was activated from occipital (O1, O2) and partial (P3, P4) area. Therefore, parieto-occipital area of brain are active in both resting and action state of brain. However cross coherence tells that there is more coherence between right and left hemisphere in action state of brain than that in the resting state. The preliminary result indicates that these potentials arise from the same generators in the brain.

Keywords: Action State, Cross Coherence, Dipole Source Localization, Electroencephalogram (EEG), Independent Component Analysis (ICA), Resting State.
PACS: 87.19.le ,87.85.D-

INTRODUCTION

The Electroencephalogram (EEG) is one of the most important tools for accessing the most unknown and complex system in nature. It is a visible record of the amplified electrical activity generated by nerve of the brain. EEG gives good temporal resolution and therefore great details about time information in the brain can be revealed. However due to its low spatial resolution many researchers had increased the number of pickup electrodes in order to locate the EEG signal sources particularly to study the differences between open and close eyes conditions [1]. Different methods, such as power spectral analysis of EEG signals in open and closed eyes [2] and alpha activity in occipital lobe, are employed to analyse EEG signals. In 2007, R. J. Barry et al. [3] used a Fourier transform to analyse EEG signals for open and closed eyes states. This study reported that, the topographic changes were existed 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 2009, R. J. Barry et al. [4] conducted another study about arousal versus 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.

Independent component analysis (ICA) has been used for EEG analysis in recent years [5, 6]. ICA identifies temporally independent signal sources in multi-channel EEG data as well as their pattern of projection to the scalp surface. It has been proven to be effective in removing the artifact from EEG signal such as blinks [7], eyes movement, muscle activity and speech artifact [8] which are very common noises in EEG signals.

Due to the lack of spatial resolution of EEG, dipole fitting model is proposed to evaluate and localize the source of EEG intra-cerebral electric sources [9]. Several theoretical studies indicated that a more dense sampling of the scalp electric fields should lead to a better accuracy of the source localizations [9, 10]. It is important not only that a sufficient number of electrodes are used, but also the electrodes should provide an adequate coverage of all areas of the brain. Moreover, different conduction properties such as vivo human brain to skull conductivity ratio also play an important role [11]. Other studies such as epileptic spikes localization [12, 13] are empirically trying to characterize the neural generators responsible for experimental effects detected on the scalp sensors. Clinical studies and combination with PET, SPECT and EEG-fMRI showed very reliable localization in pre-surgical patients and therefore increases our understanding of certain epileptic syndromes [14].

In this work, brain sources localization dipole fitting is discussed in order to characterize the source of signal generator in resting and action state of brain. It also aimed to investigate hemispherical coherency and symmetricity

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constrain of dipole for different electrical sources. Such study is helpful in monitoring of cognitive brain process due to the ability of dipole fitting model for estimating the current sources in different states of brain.

METHOD AND EXPERIMENT

Participants

Twelve young students, from Department of Physics, Universiti Teknologi Malaysia, have 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 Laboratory, the Department of Physics, Universiti Teknologi Malaysia.

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 [11]. 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 electrodes (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 channel locations. Furthermore, the dipole fitting of ICA are applied using DIPFIT2 EEGLAB extension and by applying a boundary head method for fitting in resting and action state of brain.

Dipoles Fitting

In order to assess source location of EEG in resting and action state and to evaluate if they are generated from the same source, dipole fitting model is utilized. DIPFIT2 extension plugged into EEGLAB Matlab toolbox can be used to perform source localization by fitting an equivalent current dipole model using a non-linear optimization technique. Standardized boundary element head model is chosen, it perform Localization within a three-shell boundary element model (BEM) of the Montreal Neurological Institute (MNI) standard [15]. Rejection threshold is an important parameter to care about; it does allow setting a threshold on the maximum residual variance (RV) that is accepted. Using this threshold, components that do not resemble a dipolar field distribution will not be assigned a dipole location. Not solely the Residual Variance (RV) but other criteria should be taken for a good source model. Rather, the agreement of source model with proven knowledge about the underlying brain activity (e.g. activation of the visual cortex after a visual stimulus as opposed to a single brain area). The obtained residual variance is less than 1%, indicating that this source models data are accurate.

RESULT AND DISCUSSION

The analysis focused on scalp potentials in continuous recorded EEG (long latency range) in resting and action state of brain. A detailed study on topography scalp distributions, Cross Coherence, ICA and dipole fitting source localization are discussed.

The power spectrum analysis is higher in Parietal and Occipital area in both resting and action state of brain when their eyes are closed, and these showed good agreement with the literature [16]. The activation of the brain lobe is based on the maximum frequency spectrum available at a specific electrode position. Also it is very difficult to differentiate between these two states since they are very close to each other in their frequency spectrum. In open eyes condition, the highest power spectrum was at the frontal lobe as reported previously, substantial frontal alpha exists in healthy adults with relaxed states as well as in many patients awake prior to surgery [17]. The frontal lobe is active with a higher power at low frequency and reduces gradually as the frequency increases. The higher power is noticed on the Parietal and Occipital lobes for close eyes condition, while the prominent peak remained around 10 Hz in both states (Figure 1). That's indicating activation of alpha wave during close eyes condition. This result supported that Parieto-Occipital alpha waves during periods of eyes closed are the strongest EEG brain signals [3, 18]. Scalp topography shows the brain activity and scalp distribution in both states, but it cannot easily differentiate between these states. For this reason, we suggested to apply cross coherence between active channels as shown in Figure 1, which discusses the result of cross coherence between EEG channels. The cross coherence between channels versus frequency are plotted, the left column for the resting state and the right column for the action state. As its clear the cross coherence between the channels observed with a sharp peak around 10 Hz. Also, there is more cross coherence between channels in action state than in resting state. This result indicates that, there is more coherence between right and left hemisphere in action state of brain than that in the resting state.

To localize the sources of EEG; based on the scalp topography Parietal and Occipital area focused; the four channels (P3, P4, O1 and O2) are discussed. ICA is applied to these channels as in figure 2. ICA using un-mix matrix to identifies temporally independent signal sources in multi-channel EEG data as well as their pattern of projection to the scalp surface. ICA components have been shown to be significantly more like dipolar than the raw EEG or any ERP (Event Related Potentials) even though neither the locations of the electrodes nor the biophysics of volume propagation are taken into account by ICA [19]. Figure 2 show the component map with the electrodes positions are marked on the Parietal and Occipital lobes.

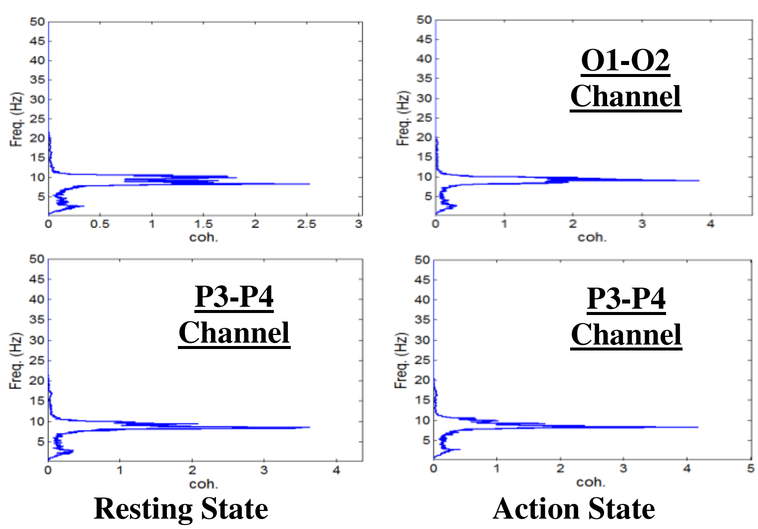

FIGURE 1. Cross Coherence Between Channels in Resting State on the Right and Action State on the Left.

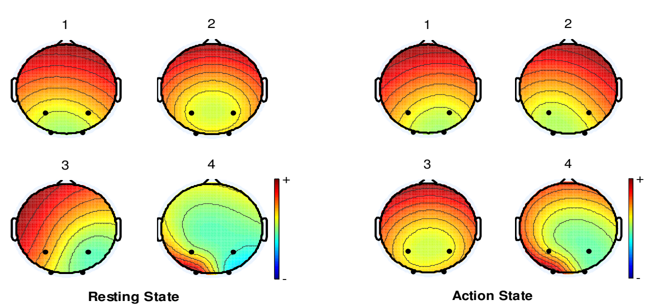

FIGURE 2. Independent Component Analysis Map in Resting and Action State of Occipital and Parietal Four Selected Channels.

To evaluate the current source of selected component with nonlinear dipole fitting model, first the head model is set, followed by auto fit the model (fine fit, coarse fit and plot the dipoles) as in figure 3. Those four sources are marked for each state. The equivalent current dipole described by three important parameters, these are Position, Strength and Orientation. Dipole source position described by the spheres of the dipoles orientations and the directions of currents flow are shown from the sphere to the end of the dipole vector. These sources analysis revealed four dipolar sources, one associated with visual- partial area (green color), one close to the junction between frontal-partial area (blue color), the third dipole with post central gyrus (red color) and fourth (pink color) is a part of frontal cortex, it's just interior to premotor cortex. As shown in figure 3, the dipoles are located almost in the same place in resting and action states. This indicated that those dipoles are generated from the same source.

Figure 4 shows the symmetry constrains of dipoles of right and left hemispheres. Potentials were projected onto both hemispheres, to enable analysis pairs of dipoles [20]. Localization was performed and sources were fitted to locations almost on the partial region since it prominent region of sensation. The dipole orientations of the sources were more radially oriented and this result conforming previously reported study indicated that EEG is more sensitive to radial than to tangential dipolar electrical sources [21].

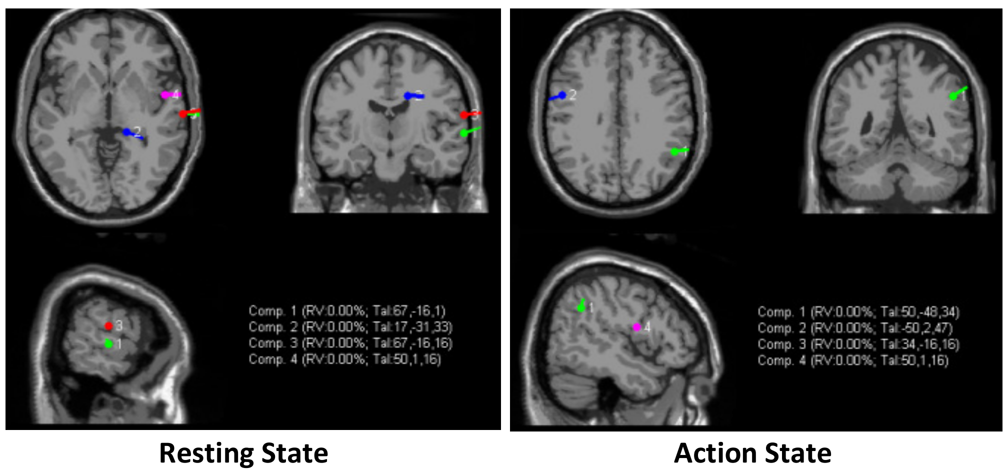

FIGURE 3. Dipoles Fitting of the Components, Four Components for each State.

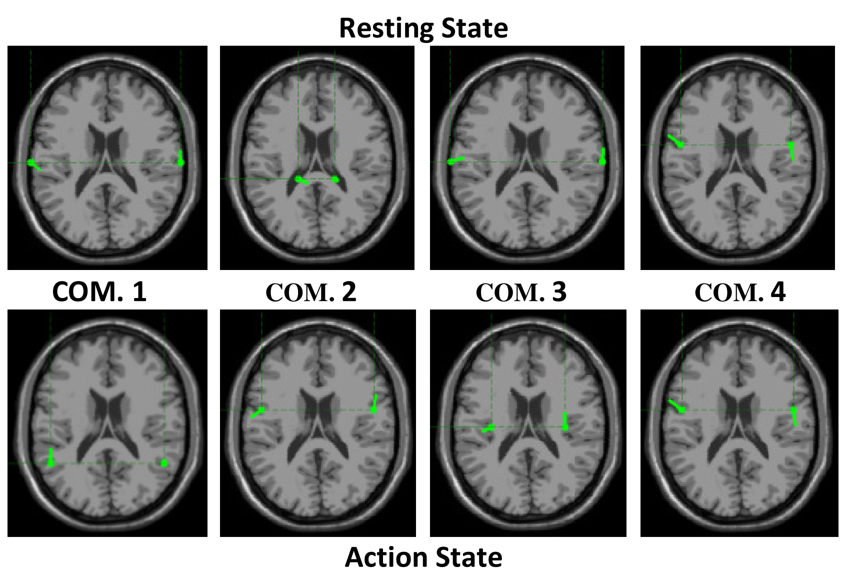

FIGURE 4. Symmetry Constrain of Dipoles of both Hemispheres (Pair Dipole Fitting).

CONCLUSION

The present study discussed and analyzed EEG signal in resting and action state of brain. Topographical brain distribution, power spectrum analysis and time- frequency cross coherence analyses are used to distinguish between resting and action state of brain. Dipole fitting model is used to localize the sources of EEG generated in brain. The brain topography result showed that Parieto-Occipital area of brain are active in both resting and action state of brain. However cross coherence tells that there is more coherence between right and left hemisphere in action state of brain than that in the resting state. The estimated dipole sources indicate that these potentials in resting and action state are generated from the same sources. The sources were fitted and localized almost on the partial region since it prominent region of sensation.

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