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BSPC-1051; No. of Pages 17
ARTICLE IN PRESS
Biomedical Signal Processing and Control xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Biomedical Signal Processing and Control
journal homepage: www.elsevier.com/locate/bspc

A novel method for tracking and analysis of EEG activation across brain lobes

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ARTICLE INFO

Article history:
Received 7 February 2017
Received in revised form 24 May 2017
Accepted 30 June 2017
Available online xxx

Keywords:
Brain lobes
Electroencephalography
Activation
Topo-maps
Optical flow estimation
Tracking
Oddball paradigm
Correlation

ABSTRACT

Electroencephalography (EEG) measures the electrical activity of brain that is generated by the synchronized activity of thousands of neurons. In this paper, our first goal is to develop a novel method to **track** the EEG activation in different brain regions involved in the processing of target and non-target stimuli in oddball paradigm. Secondly we want to identify the difference in the pattern of activation for different oddball tasks. The EEG data has been acquired from twenty healthy volunteers for the visual oddball experiment. In the task two types of visual stimuli target (rare) and non-target (frequent) were randomly presented. The subjects were instructed to press the enter button when they identify the target stimuli. The EEG data acquired is converted into EEG topo-maps. In our method the flow of activation between consecutive topo-maps is estimated by using Horn and Schunck Optical Flow estimation method. It helps to generate the motion field between consecutive topo-maps which is considered as flow of activation between two time frames. Different motion vectors are clustered into a group based on the activation level. These clusters are tracked between different frames as a measure of the activation flow. Finally we analyze the flow of activation across different brain lobes for different cases encountered in the Oddball paradigm by plotting average activation graph with respect to time. **Analysis** of the data has revealed that high activation has been observed in the Frontal and Occipital lobes in general for the oddball task. Frontal lobe shows high activation for target with response case, this is followed by the Occipital lobe. The activation in frontal lobe starts increasing from frame no 60 (240 ms) (out of 125 frames). Occipital lobe shows high activation for target with no response and no target no response cases in the region from 40 to 60 frames. Parietal lobe shows high activation for target with response near the end of task from frame no. 100 onwards. Hence, we have been able to identify different patterns in the activation flow that differentiates different Oddball tasks. This activation pattern is consistent with the event related potential signal generated by the Oddball paradigm. The pattern for the individual subjects also follow the average pattern of high activation in the frontal and occipital region for target and non target stimuli. We have also used cross correlation (a classical connectivity method) for comparison of the results. A subjective comparison of the results show that our proposed method is capable of tracking the EEG activation.

1. Introduction

Brain is one of the most complex organs in the human body and is the main organ in the central nervous system. It generates signals to control various functions in the body. The cerebrum, the cerebellum, and the brain stem constitute the three main parts of the brain. The cerebrum is divided into four distinct lobes named as; frontal (F) lobe, parietal (P) lobe, temporal (T) lobe, and occipital (O) lobe. Each lobe is characterized by its own specific function. The primary motor (M) cortex lies in between the frontal and the parietal lobe. It is responsible for planning, control, and execution of the voluntary movements [1]. Fig. 1 shows different brain lobes and Table 1 gives a brief summary of their functions.

An electroencephalogram (EEG) detects the electrical signals in the brain with the help of electrodes placed along the scalp. EEG basically measures the fluctuations in the voltage signals generated by the firing of the neurons (order of micro-volts). The main advantage of EEG is that it has very high time resolution, hence it is able to capture the cognitive processes in the same time frame as the cognition occurs. Cognition, emotional and motor processes are normally fast. Most of the cognition processes occur within ten to hundreds of a millisecond. The events that trigger cognitive pro-

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http://dx.doi.org/10.1016/j.bspc.2017.06.017
1746-8094/

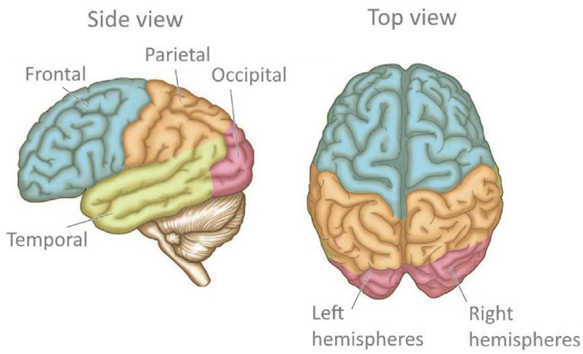

Fig. 1. Different brain lobes [1].

Table 1
Function of different brain lobes.

Brain Lobe	Functions
Frontal	Involved in planning, decision making, problem solving, movement and emotions
Occipital	Involved in visual processing
Parietal	Involved in recognition, perception of stimuli, movement and orientation
Left Temporal	Involved in processing of verbal memories
Right Temporal	Involved in processing of nonverbal memories

cess occur in time sequences that span 100 of milliseconds to a few seconds [2]. In addition to EEG, functional Magnetic Resonance Imaging (fMRI) is also used to measure the activity in the brain. This technique makes use of the fact that cerebral blood flow is directly related to neuronal activation. Hence when an area in the brain is in use; the blood flow to that region increases. This technique can localize activity to within millimeters but no better than within a window of a few seconds. Resting state functional connectivity is often computed via Pearson correlation of fMRI blood oxygenated level dependent (BOLD) signal time series recorded at different voxels [3]. Newer methods which improve both spatial and time resolution are being researched. Hence EEG has the advantage of good temporal resolution whereas fMRI has good spatial resolution.

EEG topography is a neuroimaging technique in which mapping of the electrical activity across the surface of the brain is done by placing a large number of EEG electrodes on the head. EEG topographic maps can display raw EEG data such as voltage amplitude, power or peak latency that are derived parameters. The term brain connectivity, commonly used in neuroscience refers to a pattern of anatomical (structural) connectivity, functional connectivity or effective connectivity within the nervous system in the brain. Structural brain connectivity is related to the network of physical structures linking the neuronal elements. These connections are relatively stable at shorter time scales that range from seconds to minutes, however at longer time scales of the order of hours or days the structural patterns undergo morphological changes and plasticity. Hence structural connectivity is inherently difficult to define because of the fact that existing synaptic connections disappear and new connections appear dynamically. Functional connectivity is a statistical concept that captures the deviations from the statistical independence between spatially distributed or remotely located neuronal units. Simple statistical parameters like correlation, coherence and covariance are used to measure functional connectivity. However these statistical patterns between neuronal elements occur for a very short period of time, i.e. tens of hundreds of milliseconds. Hence functional connectivity may be defined as the temporal correlation between spatially remote neurophysiological regions. Finally effective connectivity may be defined as the influence that one neural system directly or indirectly exerts on another system, it can be considered as the combination of structural and functional connectivity. Literature review has revealed that the brain connectivity can be estimated by several methods; like classical methods of finding coherence, correlation and covariance [4–6], non-linear methods; like mutual information, transfer entropy, generalized synchronization and phase synchronization, multivariate methods; like Direct Transfer function, direct Directed Transfer function and Partial Directed Coherence algorithm [7].

The aim of this research is to track the activation across brain lobes over a period of time to map functional connectivity for a cognitive task. Visual oddball experiment has been used for acquiring EEG data. Oddball experiment is commonly used for event related potential research (ERP). Many researchers have studied event related tasks using fMRI [8–11]. In [8], the researchers used a visual oddball task to investigate the spatial distribution of cortical activation in the frontal and parietal lobes. It is reported that the visual target stimuli produced robust activation in occipital cortex, in occipito-temporal regions as well in the intra-parietal sulcus (IPS-portion of parietal lobe) and supramarginal gyrus (portion of parietal lobe). Additionally, the activation produced by the visual task in the middle frontal gyrus (MFG) and superior frontal gyrus (SFG) was significantly greater than the auditory task. The MFG has been reported to respond in a number of working memory related paradigms. The greatest response to the visual targets appeared in the right middle temporal gyrus (MTG), the right MFG, bilaterally in the inferior frontal gyrus and premotor area, and in the anterior cingulate.

A study of visual oddball target detection task using the fMRI technique conducted by Brazdil et al. [9] reports significantly greater activations in response to the target stimuli as compared to the frequent stimuli in several brain regions including IPS, anterior cingulate cortex (ACC-part of frontal lobe) and prefrontal cortex (PFC). They claimed that bilateral coupling between F and P regions are present. Another study conducted by using fMRI to study visual oddball paradigm is done by [10]. They have reported visual cortex activation for target and frequent stimuli. Motor related activation was seen in the respond condition only. The network of regions involved in target detection included the pre and post central gyri regions of parietal cortex and basal ganglia and the middle and inferior frontal gyri. This is consistent with previous oddball fMRI studies. It represents attention and working memory processes associated with target detection. However authors noted that many of these regions are involved in multiple cognitive processes and determining their specific involvement in a task will be difficult.

Fukami et al. [11], studied the sources of visual stimuli using fMRI to observe the temporal change. They reported activation in the right dorsal lateral pre frontal cortex (DLPFC) in the later part of the experiment. DLPFC is related to the working memory. They found that the consumption of working memory in the target stimulus is larger than the non target stimulus. They also found that the parietal area gets activated earlier than pre frontal. They also detected some activation in the left motor area because button pressing was required.

Most of the research related to functional connectivity analysis makes use of a constant time window to track the dynamics of functional connectivity as estimated by the EEG recordings. These algorithms are may not be able to track changes over very short durations (of the order of 500 ms), as in the case of responses evoked from visual stimuli. The excellent temporal resolution of EEG allows us to track the dynamic properties of cognitive processes, this has not been researched a lot [2]. High resolution EEG is used in [2,12] to track the functional connectivity of brain associated with a picture naming task. The algorithm is based on k-mean clustering theory of the connectivity graphs obtained from phase locking value (PLV) method. The results show that the evoked responses can be divided into six clusters representing distinct networks sequen-