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Source localization algorithms to find attention and memory circuits in the brain

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Abstract Brain is a complex organ and many attempts have been done to know its functions. Studying attention and memory circuits can help to achieve much information about the brain. P300 is related to attention and memory operations, so its investigation will lead to better understanding of these mechanisms. In this study, EEG signals of thirty healthy subjects are analyzed. Each subject participates in three-segment experiment including start, penalty and last segments. Each segment contains the same number of visual and auditory tests including warning, attention, response and feedback phases. Data analysis is done by using conventional averaging techniques and P300 source localization is carried out with two localization algorithms including low-resolution and high-resolution algorithms. Using realistic head model to improve the accuracy of localization, our results demonstrate that the P300 component arises from a wide cerebral cortex network and localizing a definite generating cortical zone is impossible. This study shows that a combination of high-resolution and low-resolution algorithms can be a useful tool for physiologists to find the neural sources of primary circuits in the brain.

1. Introduction

Contribution of the brain neural circuitry to cognitive processes is one of the main aspects of neuroscience which is so difficult in practice, and many attempts have been made to describe the function of the brain. Electroencephalogram (EEG) (Nunez and Srinivasan, 2006; Sanei and Chambers, 2007) signals are produced by recording brain electrical activity through scalp electrodes and because of convenience and low cost they still have a remarkable value in brain activity monitoring (Parvinnia et al., 2014).

Event Related Potentials (ERPs) (Polich, 2007; Luck, 2005) reflect the brain electrical responses to different sensory, cognitive or affective stimuli. Compared to functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), ERPs have better temporal resolution but less definite

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spatial resolution. By increasing the number of scalp electrodes theoretically we can improve their spatial resolution. However, it should be considered that when the number of scalp electrodes is increased, the inter-distances between electrodes are decreased (or the cross-talk among them is increased). The most well-known component of ERPs is the P300 which is in close relationship with memory/attention activities of the brain. Using depth electrodes in medial temporal regions in epileptic patients, the hippocampal formation was demonstrated as the source of P300 for the first time (McCarthy et al., 1989). But other studies on patients that had temporal lobectomy or severe medial temporal lobe injury showed that the hippocampal formation cannot be the exclusive source of this wave (Molnar, 1994). An interaction between frontal lobe and hippocampal/temporal parietal region was known as the generator of P300 (Knight, 1997; Kirino et al., 2000). Involvement of frontal, parietal, temporal and cingulate areas as the P300 source was confirmed with fMRI studies (Stevens et al., 2000).

Many algorithms have been made for reconstructing the current source for a given scalp electrical distribution. Source localization based on scalp potentials requires a solution to an ill-posed inverse problem with many possible solutions. A good understanding of brain physiology is critical for selection of a particular solution (Sanei and Chambers, 2007). EEG source localization methods can be categorized into two main approaches: equivalent current dipole approach, in which the EEG signals are assumed to be generated by a relatively small number of focal sources, and the current distributed source approach, in which all possible source locations are considered simultaneously.

The distributed source approach has good consistency with neuroimaging studies, so it could be significantly useful in determining the underlying sources of P300. Among this approach, localization algorithms such as low resolution electromagnetic tomography (LORETA) (Sabeti et al., 2011; Pascual-Marqui et al., 1994), standardized LORETA (sLORETA) (Pascual-Marqui, 2002), focal underdetermined system solver (FOCUSS) (Gorodnitsky et al., 1995) and shrinking LORETA-FOCUSS (Liu et al., 2005) have been proposed.

Mulert et al. (2004) used LORETA in the analysis of P300 data and found a large similarity between the result of LORETA and previous fMRI or intracranial recordings studies. Volpe et al. (2007) applied LORETA to analyze the two P300 sub-components (P3a and P3b) and found that P3a is related to the automatic allocation of attention, while P3b reflects the effortful processing of task-relevant events. Schimpf and Liu (2008) used SSLOFO to localize the P300 ERP neural generators. They showed that the results are in line with functional neuroimaging studies while preserving the temporal resolution advantages of the EEG.

Li et al. (2009) applied EEG/fMRI integration to investigate the neural sources of P300 component. Their results revealed that P300 was generated in a distributed network such as bilateral parietal, middle and inferior frontal, precentral, postcenteral cortex and anterior cingulate gyrus. Connell et al. (in press) studied neural sources of P3a and P3b components with simultaneous EEG/fMRI recordings for visual oddball task and showed that the effect of age on P3a component was increased activation of the left inferior frontal and cingulate cortex and decreased activation of the inferior parietal cortex. This effect on P3b was the increased activation of the left temporal regions, right hippocampus, and right prefrontal cortex.

In this study, visual and auditory paradigms are used to record P300 ERP in a group of healthy participants. Whereas the neural sources of P300 component are not determined certainly, localization of brain sources of this component is the main goal of this work. In our study, sLORETA and shrinking sLORETA are used to localize the cortical distribution of P300 generators. To improve the accuracy of localization, we used the realistic head model instead of spherical model to estimate the lead-field matrix. Also, we restricted source space (solution space) to parts of the brain that believed they are related to attention and memory circuits. Finally, the results are compared and discussed.

The paper is organized as follows. Section 2 will discuss data collection. In Section 3, we present EEG source localization algorithms. Experimental results that show the neural sources of P300 component, are introduced in Section 4. Finally, Sections 5 and 6 summarize the contribution of this paper and some future research directions respectively.

2. Data collection

Thirty normal subjects (20 male and 10 female) aged between 18 and 30 years (23.10 $\pm$ 3.84 year) participated in this study. All participants were students and they were recruited from Shiraz University, Shiraz, Iran. Each participant has been seated upright with eyes open and the experiment lasted around 150 min. To avoid any muscle artifact the neck was firmly supported by the back of the chair, and the feet were rested on a footstep.

Each subject participated in three-segment experiments including start (takes about 30 min), penalty (60–90 min) and last (30 min) segments. Each segment contains an equal number of visual and auditory tests where each test includes warning, attention, response and feedback phases. Fig. 1 shows a simple illustration of the visual test. At the beginning of each test, the participant sees two up and down flashes, as an alarm. In the attention phase, one of the flashes appears. In the response phase, a question mark appears and the participant must answer which flash has appeared by pressing up or down button. In the feedback phase, a right/wrong answer is displayed. The auditory test is similar, in structure, to the visual test, but the participant distinguishes between low or high pitch tones from the background white noise. The visual and auditory tests are applied alternatively, and to start the next test, participants must press a button. Each visual or auditory test lasts about 7 s. In this work, each segment contains one hundred visual tests and one hundred auditory tests. In penalty

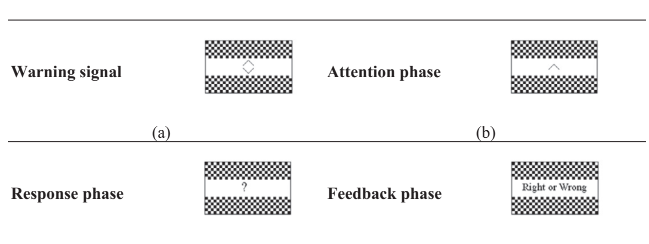

Figure 1 Illustration of visual experiment.