

Separation of p300 sources and their subcomponents to study the impact of numeration on visual attention; using constrained blind source separation

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Abstract- Attention and numeration are two phenomena in cognitive sciences of brain. As the effect and interaction that these two activities have on each other, the importance of detecting differences between two phenomena is shown more than ever. Someone believes that the relation between two brain cognitive activities (i.e. attention and numeration) is close to the extent that they are considered as one. In most of past works, the qualitative effect of numeration or extra mental task on attention is surveyed. The aim of this article is to clarify differences between two phenomena and the effect of extra mental activity (numeration) on visual top-down attention. For this purpose we separate P300 sources signal and their subcomponents to divide two classes (attention with numeration and pure attention). To do this, constrained blind source separation (CBSS) is used. The main method is to use Infomax algorithm that beside it, minimizing the difference between reference and estimated signal P300 and also subcomponents, P3a and P3b, are used as constrained term. The obtained result indicates that time of appearance and amplitude of estimated signal P300 and their subcomponent for two class are different. By doing paired t-test, best result for divided two cognitive activities, were obtained by amplitude of estimated p300 with P-value 0.01. To our knowledge, Seen from this aspect to this subject, is a new effort.

Keywords- Visual attention; numeration; P300; p3a; p3b; CBSS; infomax; P-value

I. INTRODUCTION

Attention is the most challenging cognitive sides of brain in terms of nature and processing and analyzing data. One of its tangible definitions is that: cognitive process of selective concentration on one side of environment, in spite of ignoring another sides and removing the effect of some factors (deviating) to investigate effectively the considered factors. In addition, counting is also a mental activity. Someone believes that these two cognitive activities are very close to each other to the extent that mostly in their researches for making attention state, the subject is asked to join counting the with subject's act [1].

ERP is the most direct existing non-invasive methods to survey brain activities that are obtained by synchronous

averaging from signals EEG that are registered during repetition of stimulation object. P300 is one of the most prominent components of ERP during cognitive activities of brain that whenever the brain is processing a series of innocuous stimuli and collides to the unusual stimulation (target stimulation); it is appeared in recorded brain signal.

For visual stimulation, appearance delay time of this positive peak is increased till approximately 1000 milliseconds after novel stimulus onset. In most of pervious work as terms of place, P300 is recorded on head midline and in most cases has the most amplitude in parietal area [2]. However, P300 includes also overlapping two subcomponents P3a and P3b. P3a is involuntary reflex to the new, prominent and independent towards primary task [3, 4]. In producing P3a, frontal lobes and temporal anterior play the main part [3, 5]. But P3b has more distribution in part of posterior temporal, parietal and rear part of gray cortical. Also P3a is occurred with low delay compared to P3b [5, 6].

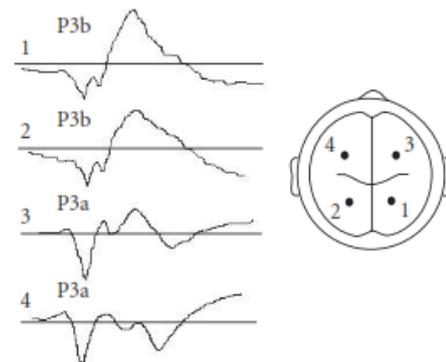


Figure 1. Some examples for p3b (1 and 2) and p3a (3 and 4) signals and their corresponding typical locations.

Movement of these subcomponents can be the base of difference between brain activities. For example, separation and localization of components P300 and their subcomponents are used in some articles to survey and distinguish schizophrenic illness [7].

By searching in past researches, it is determined that a lot of works are done in attention field. But researches are very

limited based on signal analysis for making difference between two mental activities of attention and numeration and their effect on each other [8]. As said, in most of projects, in defining and designing experiment to attend primary definition state, attention is used with counting.

In this article, to survey the numeration effect on attention, it is tried to separate reference signal P300 and their subcomponent from electrode signals in two states of pure attention and attention with counting and also tried to represent their differences.

II. MATERIALS AND METHODS

A. Data

In this article, we use recorded data from Davoodi thesis. The protocol is performed on 45 subjects (22 women, 23 men) with a mean age of 21, 68 ± 2 , 39 years. Condition and structure of experiment is as following

100 pictures including 10 pictures of human face, 10 fruit pictures and 80 scenes pictures are selected. These pictures represents blow by blow.

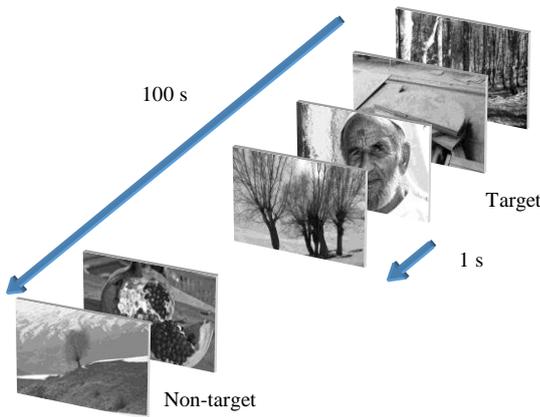


Figure 2. Example of the stimulus sequence [9]

Used data in this article are in aware state. To make this state, each picture is shown for one second. In the following, there are three phases. In first phase, the subject does not have any information referred target and non-target pictures and only is the observer of pictures. Target pictures according to our definition for subject are face pictures and next time are fruit pictures. In the second phase, subject is asked to pay attention to the object pictures. In third part, the subject is asked to count object pictures in addition of attending. Brain signals are recorded on head using 8 active electrodes and based on standard 20-10: O1/O2, PO8/PO7, P6/P5, and F3/F4. This experiment was a part of a complex task and more details of it could be found in [9].

After that primary preprocessing are performed. ERP with 1200 milliseconds (200 milliseconds before and 1 second after start of stimulation) are obtained. After extraction of ERP, there are 4 signals for each person. These signals are

categorized into two classes. As each two signals is located in one class with the same label of mental.

TABLE I. TWO SUBSEQUENT CLASSES OF ATTENTION

	Mental task	Target stimuli
Visual attention	attention to target images	10 fruit images + 10 face images
	attention to target images + Counting the number of targets	10 fruit images + 10 face images

B. Blind source separation

Blind source separation is used to determine components of ERP. The aim of BSS is to separate source signal, $s(t)=[s_1(t), s_2(t), \dots, s_n(t)]$, from electrode recorded signals, $x(t)=[x_1(t), x_2(t), \dots, x_m(t)]$. H called mixing matrix that make relation between source and electrode signals.

$$x(t) = Hs(t) \quad (1)$$

Different algorithms are designed to do this. in most cases a matrix $W=H^{-1}$ is used to estimate the sources indirectly. In the below equation, $y(t)$ denotes the estimate of $s(t)$.

$$y(t) = Wx(t) \quad (2)$$

The first method to achieve reference estimation P300 is using the method of least squares [10, 11]. ICA is the next suggestion of researchers. In this method, it is tried to estimate reference considering references independence [12, 13]. The main method in this article is Infomax algorithm [7]. The infomax cost function is

$$J_m(W) = I(z, x) = H(z) - H(z|x) \quad (3)$$

This algorithm attempts to maximize the information flow ($I(z, x)$) between the input (electrode signal) and output (nonlinear transformation of estimated sources) of artificial neural network (ANN). The natural gradient of (3) is

$$\nabla_w I(z, x) W^T W = \nabla_w H(z) W^T W \quad (4)$$

The adaption form of unmixing matrix W becomes

$$W_{t+1} = W_t + \mu(I + (1 - 2f(y))y^T)W \quad (5)$$

Where $z = f(y) = (1 + \exp(-y))^{-1}$ and μ is learning factor. But in addition, improving reference extraction method P300 and their subcomponents are done by performing constraints. Lagrange multipliers (Λ) incorporate the constraint function into main cost function. Minimizing the difference between reference and estimated signal P300 and also subcomponents P3a and P3b are used as constrained term [7]

$$\max J_m(W) \text{ subject to } J_c(W) = 0 \quad (6)$$

So, the cost function of CBSS algorithm is

$$J(W, \Lambda) = J_m(W) - \Lambda J_c(W) \quad (7)$$

For each column of unmixing matrix is defined as

$$J_c(w_i) = \sum_{t=1}^P (y_i(t) - r(t))^2 \quad \text{for } i = 1, \dots, m. \quad (8)$$

Where $r(t)$ is the reference signal. In the following, adaptively form of W is found

$$\begin{aligned} W_{t+1} &= W_t + \mu(\nabla W_t J(W_t, \Lambda)) W_t^T W_t = \\ &= W_t + \mu(I + (1 - 2f(y))y^T) - 2\Lambda (x(W_t x - P)^T) W_t^T W_t \end{aligned} \quad (9)$$

$$\Lambda = \rho \text{diag}((Wx - P)(Wx - P)^T) \quad (10)$$

In this relation μ is learning factor, ρ is a scale factor for Lagrange multiplier and P is matrix whose rows contain the reference p300 signal.

Up to this point, we separate p300 sources. For p3a and p3b can present several algorithm. In this paper, we use method of least squares. As before we can model the reference (r) and electrode signal (X) of EEG [7]

$$r = w_{opt} X \quad (11)$$

The constrained cost function will be

$$J_c(w_i) = \|w_i - w_{opt}\|_2^2 \quad (12)$$

The gradient of (12) is

$$\nabla_{w_i} J_c(w_i) = 2(w_i - w_{opt}) \quad (13)$$

W_{opt} is found using common least-squares (LS)

$$w_{opt}^T = (XX^T)^{-1} Xr^T \quad (14)$$

C. Construction of reference signals and detection of p300 and their subcomponent

To obtain and separate components of P300, we should have reference signal. To do this, first by using ERP signal, delay time of appearance p300, P3a and P3b are obtained. For p300, as previously mentioned, in visual stimulus its appearance in 300 till 1000ms after target-stimulus. So we consider sinc with 600ms delay as reference signal. It is shown in Fig 3.

Averagely, P3a is occurred with delay 260 and P3b with delay 300 milliseconds. So, the first positive peak of ERP signal that is about 250 to 350 milliseconds goes to P3a and next positive peak is considered as P3b. Reference signals P3a and P3b as sinc signal with maximum height are considered that are obtained in times. The reference signals are shown in Fig 4 and Fig 5.

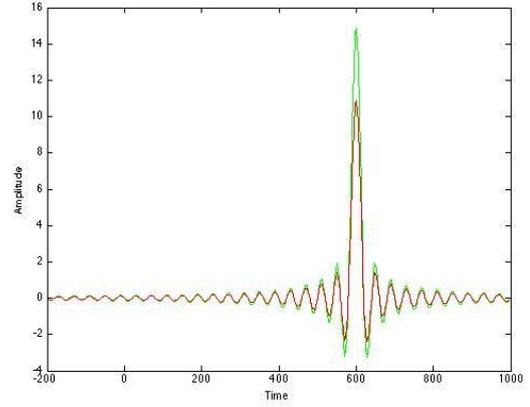


Figure 3. Reference signal of p300 for two class, red wave belong to pure attention, green wave belong to attention with numeration

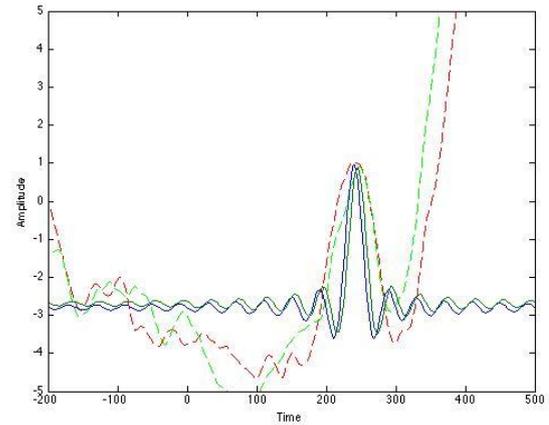


Figure 4. ERP and Reference signal of p3a for two class, dashed red wave belong to ERP of pure attention, dashed green wave belong to ERP of attention with numeration. Soiled blue wave belong to p3a reference of pure attention and soiled dark green wave belong to p3a reference of attention with numeration

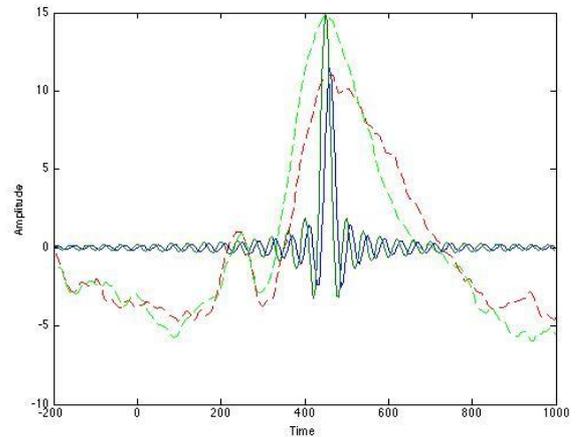


Figure 5. ERP and Reference signal of p3b for two class, dashed red wave belong to ERP of pure attention, dashed green wave belong to ERP of attention with numeration. Soiled blue wave belong to p3b reference of pure attention and soiled dark green wave belong to p3b reference of attention with numeration

After separating references, correlation of reference signal P3a and P3b are obtained with estimated signal. Finally, estimated reference signal that has the most correlation coefficient with reference signal P3a and P3b, is the designed estimated.

D. Statistical Analysis

After the signal estimation of p300, p3a and p3b, the significant difference between the two classes (P-value) were examine for all features by applying one-sided paired t-test. Features are height and timing of the peak of each estimated signal.

III. RESULTS

In first figure of this part, Two-class grand average ERP waveforms were shown.

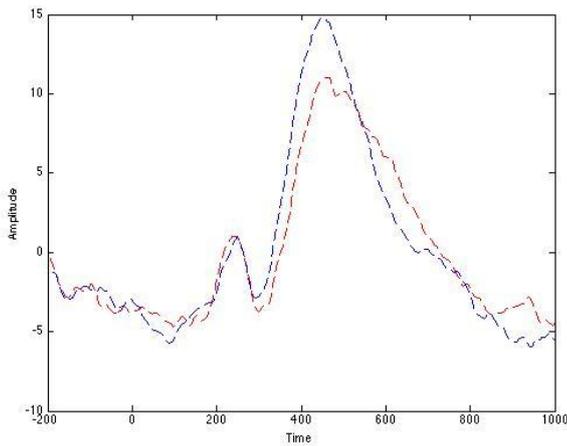


Figure 6. Two-class grand average ERP waveforms. Red wave belong to pure attention, green wave belong to attention with numeration

Estimated p300, p3a and p3b sources for two classes (pure attention and attention with numeration) can be seen in Fig 7, 8 and 9 respectively.

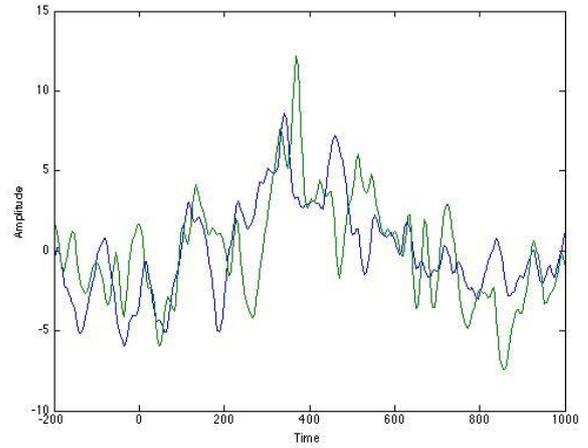


Figure 7. Estimated p300 signal for two class. . Blue wave belong to pure attention, green wave belong to attention with numeration.

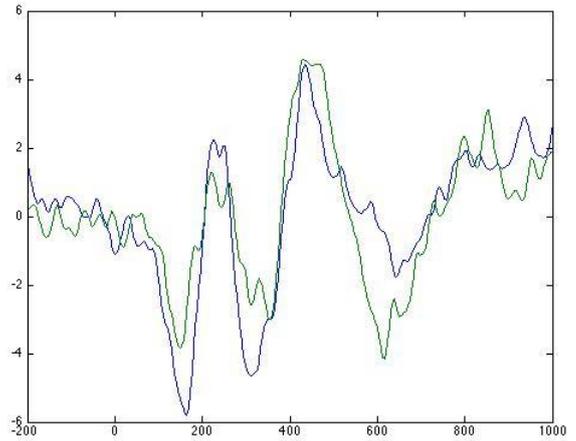


Figure 8. Estimated p3a signal for two class. . Blue wave belong to pure attention, green wave belong to attention with numeration.

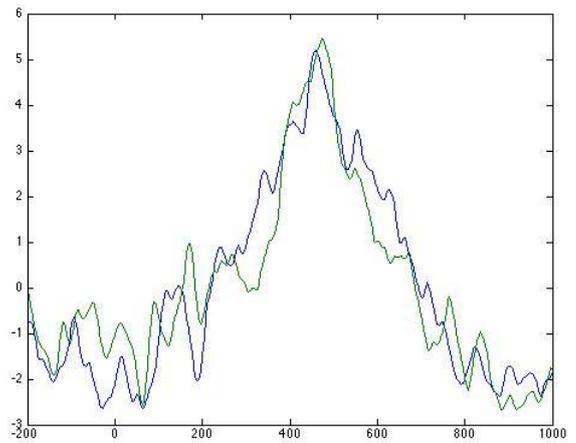


Figure 9. Estimated p3b signal for two class. . Blue wave belong to pure attention, green wave belong to attention with numeration.

After applying paired t-test, best result of feature obtained in peaks of estimated signals and the delay time have not enough

information to divided two class. Three top result that selected by P-value were shown in Table II.

TABLE II. RESULT OF STASTISTICAL ANALYSIS

feature	P-value
Peaks of estimated p300	0.01
Peaks of estimated p3a	0.07
Peaks of estimated p3b	0.05

IV. DISCUSSION

In current study visual attention and extra cognitive task (i.e. numeration) were considered. We separate P300 sources signal and their subcomponents to divide two classes. As it was shown after estimation and separation p300, p3a and p3b, we could see difference between those signal in extra mental task (numeration) and pure attention. We show that in state of attention with numeration, height and delay of appearance p300 in brain increase. This difference between two classes were seen in p300 subcomponent estimated, too. But with statistical analysis, we determinate that just peaks of estimated signal have Meaningful difference and time of delay have not very significant information. Best result have obtained of peaks of estimated p300 with P-value 0.01. So again it was shown the difference between these two phenomena (i.e. attention and numeration).

ACKNOWLEDGMENT

The data used in this paper were provided by Raheleh Davodi during her MSc. Thesis. The authors like to acknowledge her support for sharing data.

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