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N1 WAVE IN THE P300 BCI IS NOT SENSITIVE TO THE PHYSICAL CHARACTERISTICS OF STIMULI

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One of the widely used paradigms for the brain-computer interface (BCI), the P300 BCI, was proposed by Farwell and Donchin as a variation of the classical visual oddball paradigm, known to elicit the P300 component of the brain event-related potentials (ERP). We show that this paradigm, unlike the standard oddball paradigm, elicit not only the P300 wave but also a strong posterior N1 wave. Moreover, we present evidence that the sensitivity of this ERP component to targets cannot be explained by the variations of the perceived stimuli energy. This evidence is based on comparing the ERP obtained for usual P300 BCI stimuli and for the "inverted" stimulation scheme with low stimulus related variations of light energy (gray letters on the light gray background, "highlighted" by very light darkening). Despite the dramatic difference between the stimuli in the standard and "inverted" schemes, no difference between N1 amplitudes were found, supporting the view that this component's sensitivity to targets cannot be based simply on "foveating" the target, but may be related to spatial attention mechanisms, whose involvement is natural for the P300 BCI. Efforts to optimize the P300 BCI should address better use of both P300 and N1 waves.

1. Introduction

Brain-computer interface (BCI) is a technology providing the user's brain with new output pathways [12, 26], enabling sending messages or controlling various devices without using the muscles. A user is typically trained to change the activity of his/her brain in such a way that the related change in some physiological signal can be detected by a computer and converted into commands. As such a physiological signal, the electroencephalogram (EEG) is used most often, because it provides real time non-invasive estimation of the brain activity with high temporal resolution using portable equipment, while not requires immobilizing the user's head and/or placing it into a scanner.

The main application area of this technology is assisting patients with severe neurodegenerative diseases [3, 27]. In recent years, there has been also a growing interest in the use of non-invasive BCIs for creating new types of computer games [18]. The demands from the enormously wide, diverse and active area of modern game technology may give rise to many new types of BCI, which, in turn, would open new horizons for assistive BCIs, or even for efficiently introducing BCI into completely new areas of application. In addition, BCI may inherit the ability to improve attention regulation from its precursor, the neurofeedback training, and, possibly, even make it much more efficient [11].

Most of the existing BCIs, however, require a substantial period of training (from tens of minutes to weeks) before the user may start to operate the BCI more or less efficiently. This prevents using BCI in some emergency situations and also is a serious obstacle for its wide implementation in the world of computer games. On the other hand, the skill of using BCI is usually not becoming automatic even after a long training, due to the necessity to use conscious strategies (such as: imagine left or right hand movements; imagine an arrow being drawn on a bow or an arrow shooting up from the bow; etc.; see, e.g., [17]). When a skill is not automatic, it is associated with extensive and inefficient use of the brain/mind resources [19]. One solution for the automatization problem can be provided by unconscious operant conditioning of the brain activity patterns, which we observed in a form of learning to control the intensity of three colors simultaneously [12]; however, learning of this type of control was slow, and finding the ways to speed up it evidently requires more research.

A different solution, surprisingly, has been provided by one of the oldest types of BCI, the so called P300 BCI. Its name was given by the P300 wave, which will be discussed below. This BCI was invited more than 20 years ago [4], but, surprisingly, for many years it attracted little attention. Recently, its efficiency has been recognized, and its popularity is still growing: for example, the majority of BCI-related posters at the 2009 SPR annual meeting [24] were related to this type of BCI; as another example, the two BCI papers published so far in Russian journals were both related to this paradigm [13, 16]. The potential of this BCI to provide high speed of learning of BCI use and, at the same time, high information transfer rate have been widely accepted. But it also posses a feature less often discussed: unlike in most of the other BCIs, little conscious efforts of the user is needed to control this BCI. As complicated mental strategies are not needed to translate the intention of the user into the detectable changes in his/her brain activity, the goal of achieving automatic performance with this BCI is more realistic.

In the P300 BCI paradigm the user usually watch a matrix (most typically 6x6 or slightly larger size) containing cells with letters, numbers or other characters (in this case, it is usually used for typing and can be also called the “P300 speller”), or with pictures which are typically related to some commands. The rows and columns of the matrix are highlighted (intensified, flashed) for a short time in a random order. The user attends a given cell and silently counts the number of times it flashed or at least attentively note each flash, irrespectively of was it flashed as a part of a row or as a part of a column. The inventors of the paradigm suggested that the P300 wave will be elicited in scalp EEG each time a column or row including the attended cell is flashing [4]. This wave is one of the best known components of the brain event-related potentials (ERPs). It appears as a positive deflection approximately 300 ms after the onset of the target flash, with the highest amplitude over the centroparietal area. By detecting it, the computer program may find the column and row containing the attended cell, then the cell is identified as their intersection, and the computer execute the command associated with this cell. In the case of P300 speller, for example, the letter from the identified target cell is typed.

The target-related ERP should be differentiated from the ERP elicited by non-target flashes. Both types of responses, moreover, are mixed with the background EEG, acting as a strong “noise” preventing easy detection of the target-related response. To make the detection possible, a number of responses should be usually collected for each row and column, and a pattern classification algorithm should be applied.

P300 is an automatic response and no training is needed to make it being elicited when relevant stimuli are detected. However, some training is important for the classification algorithm, to adapt it to individual features of the user’s brain activity. Thus, before starting controlling a computer with BCI, the user should participate in a “calibration” session, where he/she is asked to attend flashes of known cells. In most of the published studies related to this BCI the “calibration” typically took tens of minutes, but in a recent paper it was shown that this period can be shorten to 5 minutes [5].

Though mental counting or noting the flashes is a very simple procedure comparing to imaginary manipulations required by the most of other BCIs, the need to do it for quite a number of times before the desired letter is typed or command is executed (e.g., 15 times for rows plus 15 times for columns in [5]) still may be an obstacle for fast automatization of the skill of using this BCI. How to reduce significantly the number of the brain responses needed to be collected before accurate classification becomes possible? Interestingly, a way to do this seems to be already suggested in the seminal paper by Farwell and Donchin: “It may ... be possible to enhance the speed of the system by incorporating additional components of the ERP” ([4], p.591). But so far, to the best of our knowledge, this advise have been followed in none of many papers of their followers. The only exception is mentioning, by Sellers et al. [23], Hoffmann et al. [8] and Krusienski et al. [14] the fact that the accuracy of the P300 BCI in their work was increased due to a negative component appearing in the posterior areas prior to P300. This component, similarly to P300, had a much higher amplitude in response to targets comparing to non-targets. However, no systematic study of this component has been undertaken. A negative component with a similar latency range was analyzed in the P300 BCI paradigm by Allison and Pineda [1], but in their study the electrodes were located only at Fz, Cz, and Pz sites, where only small difference could be found. Some authors used the posterior locations without explaining for what reasons they do this (e.g., [5, 25]). Understanding of the nature of the posterior negative component in the P300 BCI paradigm could not only justify the use of the posterior locations, but, much more importantly, guide the development of the paradigm in the ways which would help to increase and/or stabilize this component’s sensitivity to targets, and also would lead to implementation of signal processing techniques possibly able to dramatically increase the performance of the P300 BCI by fine tuning to both P300 and this component, and by combined use of their features.

Sellers et al. [23] and Krusienski et al. [14], as the generators for the negative component they observed seemed to be located in visual areas, discussed the possibility that both it and the P300 wave in the P300 BCI may be modulated not only by attention but, to much extent, also by “foveating the target”. If this were the case, the ERP dependence on targets were resulting from the difference between the light energy coming to the fovea from target and non-target flashes. Such an explanation could be an argument against the P300 BCI in general, as it makes the BCI dependent on gaze control provided by muscles, and, therefore, it could not help severely paralyzed individuals. Moreover, the dependence on light energy variations could lead to the dependency of physical features of the cell content (e.g., it would be difficult to use pictures with highly different brightness in the same matrix). Although Sellers et al. [23] and Krusienski et al. [14] provided some arguments against “foveating the target” explanation, they have not undertaken any experimental test of the possible ERP dependence on the stimulus physical characteristics in the P300 BCI paradigm. It should be noted that the dependence of attention-related posterior negative components (N1) on stimuli luminance has been reported [10], thus, there is a need to check experimentally if such dependence exists specifically in the settings of the P300 BCI paradigm.

Finding the contribution of the posterior negative component to P300 BCI [8, 14, 23] seemed to be an unexpected event in the history of the P300 BCI development. This is not surprising, as little research has been so far devoted to the understanding and improvement this BCI paradigm from the psychophysiological point of view, probably due to the common belief that this paradigm is just a simple variation of the "oddball paradigm", very much studied in psychophysiology. This view was proposed as early as by the inventors of the P300 BCI [4]. More recently, Sellers et al. [22] found the dependence of the P300 waveforms at Pz electrode location on the stimulus probability (manipulated by changing the matrix size) to be consistent with the understanding of this BCI as a true oddball paradigm. No attempts have been made so far to check if there are substantial differences between the P300 BCI and the oddball paradigm *outside the P300 wave*. As the result, in many tens of journal papers further development and application of the P300 BCI methodology is based solely on optimizing elicitation and detection of the P300 wave.

The oddball paradigm is the most common experimental paradigm for eliciting P300. In this paradigm, the subject is asked to respond to some rare visual or auditory event, called "oddball" or target, or count them mentally, while "standard" or non-target events are presented more often and should not be attended. P300 is associated with the targets stimuli. All of this correspond well to the temporal organization of stimuli in the P300 BCI paradigm.

However, the temporally organized events in the P300 BCI are also organized in space domain. Non-target events cannot appear at the same location where a target event occurs, thus, for counting the target flashes it is sufficient only to detect flashes at the target location. Once the target cell is located, which happens normally before the flashing starts, there is no need to further analyze the content of the attended cell, as no change happens there other than flashes going on/off. Thus, to detect target flashes one should use selective visual spatial attention, but not employ the mechanisms for the analysis of semantic or even physical features of the stimuli. In contrast, in a typical visual oddball the targets and non-targets cannot be differentiated by their locations, as presented at the same position, but instead the visual system must analyze details of each stimulus.

These differences should lead to several important consequences. First, as the task of the visual system in this paradigm is relatively simple, one may expect good performance even with quite a high rate of stimulation, not typical for visual oddball. Indeed, this has been demonstrated in many studies related to P300 BCI. For instance, Sellers et al. [22] presented flashes each 175 ms or each 350 ms and found even better information transfer rate in the case of the shortest intrestimulus interval. Secondly, the visual attention should play important role in the paradigm, and it is worth to consider the ERP components related to it [7, 15] as a possible additional source of information for differentiating targets and non-targets. The posterior negative component mentioned above is a candidate for such a role. Finally, as there is no need to analyze any details during stimulation, the processing of the visual information can be simplified, and, due to this, little dependence of the ERP on the stimulus physical characteristics will occur. No evidence, however, has been published so far to support this latter hypothesis.

In this paper, we test the critical issue of the possible dependence of the early negative component (N1, i.e., the first considerable negative deflection) in the P300 BCI on the physical characteristics of the stimuli. Specifically, we compared the standard stimulation color scheme with a new type of the color scheme of the stimuli matrix. This color scheme, in general, was similar to one recently used by Salvaris and Sepulveda [?] but had much lower stimuli contrast. Unlike in the study of these authors, we aimed not on the improvement of the BCI performance by finding the color scheme enabling the highest performance, but on clarifying one of the important aspects in the P300 BCI paradigm's basic mechanism. Therefore, instead analyzing the BCI accuracy we focused on the ERP, mainly on the N1 component.

2. Methods

2.1. *Participants*

Ten healthy volunteers (age 19-23, five males) with normal or corrected to normal vision and without previous experience of BCI use participated in the study. They were motivated for participation by the opportunity to get an unusual experience of free spelling with the BCI in the end of the experiment. The participants were told that the better they perform the tasks, the better they and the computer program will be trained and the more successful "mind spelling" they would experience. Each of them was informed about the purpose and procedure of the study and signed informed consent.

2.2. *Procedure*

The participants sat in upright position in an armchair, viewing a standard 17-inch CRT monitor at approximately 90 cm distance from their eyes. Stimuli presentation and EEG recording were organized using BCI2000 system (Schalk et al.,[21]). Several conditions were used.

In **Standard condition**, one block of stimulating/recording was presented. The participants viewed a 6x6 matrix typical for P300 BCI (Fig. 1, left). The matrix consisted of the letters of Russian alphabet, as all the participants were native Russian speakers, plus several punctuation marks (not used in the experiment as target characters). On the top of the screen, a five letter word was shown, selected randomly from the most frequent nouns of Russian language, on the condition that each letter was presented only once. The letters of this word appeared consequently in the parenthesis after it, one at time. Appearing of a new letter in the parenthesis started a new run. Five seconds after the letter appeared, columns and rows started flashing in a random order. The participant's task was to find this letter in the character matrix, and to count silently how many times it flashed, irrespective of was its a part of flashing a row or a column. After flashing finished, there was an additional pause of 2.5 sec length, and then the next run started.

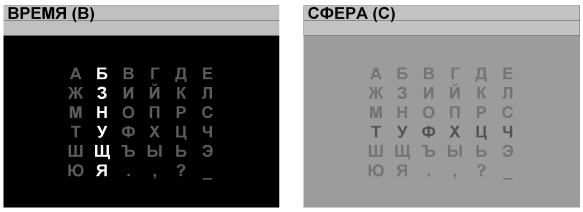

Fig. 1. P300 BCI stimuli matrix used in the experiment. Left, matrix for the Standard condition. Right, matrix for the Inverted condition. During the stimulation, the rows and columns flashed in a random order. In the left matrix, flashing of the $2nd$ column is shown. In the right matrix, flashing (darkening, for this type of matrix) of the $4th$ row is shown.

The visual angle at which the matrix was viewed was approximately at 10.5 x 8°, while the size of each character was 1 x 0.9°. The background color was black, or, more exactly, (0,0,0) in the 8-bit RGB model, the default character color was (85,85,85) (dark gray), and flashing was made by changing the character color to (255,255,255) (white). These colors followed those used in the original Farwell and Donchin [4] protocol and were common for the currently typical P300 BCI studies.

The duration of this highlighting was 125 ms, while the SOA (stimuli onset asynchrony, i.e., the distance between the beginnings of the stimuli) was 188 ms. Flashing was organized as presenting "flashing cycles" (often referred to in the BCI literature as "sequences of flashes") without pauses between them. Each of the flashing cycles consisted of flashing once each row and each column. For each character, the number of flashing cycles was set to five.

The latter parameter may deserve some notes explaining its relatively low value. Though we optimized most of the parameters of the P300 BCI stimuli, electrode locations and data analysis algorithms based on the results of recently published comparisons between various parameter sets [8, 14, 22], and, in general, our BCI configuration was similar to those used in recent studies achieving the highest efficiency (e.g., Guger et al.,[5]), we differently approached the problem of setting the number of flashing cycles. Arbel and Donchin [2] found differences between the accuracy data obtained in real time and those estimated by an offline and emphasized the insensitivity of the offline analysis to such factors as the difficulty to sustain attention within a long trial. Based on this report and on our experience, we prefer to use smaller number of flashing cycles than is typically used (e.g., 15 cycles in [5], and some other papers). We hope that, though this may lead to slightly deteriorated accuracy, the negative feedback appearing in online spelling in the form of errors can be, due to shorter time interval to which this feedback is related, easier associated by the user with variations in his/her state negatively influencing the accuracy. Though this idea still is waiting for sufficient support from experimental data, there is no reasons not to use the small number of flashing cycles at least in the basic studies of the ERP features in the P300 BCI paradigms, as it helps to reduce not only fluctuations of attention which may appear in long trials, but also the number of blinking and other artifacts.

The use of five flashing cycles meant presenting 10 target stimuli (intensifying (illuminating) the rows or columns including the attended letter) and 50 non-target stimuli (illuminating other rows or columns) per run (i.e., per one letter), i.e., 50 targets and 250 non-targets for the whole block (for one word), i.e., for the whole condition.

In **Inverted condition**, all the parameters were the same except for the colors, which were changed in the same direction as in Salvaris and Sepulveda [20] but with much lower difference between the colors (Fig. 1, right). Specifically, we used in this condition (153,153,153) (light gray) for the background, (116,116,116) (gray) for the default character color, and (85,85,85) (dark gray) for the "flashing". Importantly, the flashing not only was made in this condition by darkening instead of the usual highlighting (illuminating), but the intensity of the this color change was very low, only slightly higher than the threshold of detection of the change for the given fast rate of stimuli presentation (the temporal parameters of the stimuli were the same as in Standard condition). Such low contrast stimuli were used to provide much lower stimulation related variations of the light energy comparing to the Standard condition.

The order in which Standard and Inverted conditions were presented was random and counterbalanced across the participants. Each condition was preceded by a practice block of runs with the same setting as the condition, but comprising attending letters from a three letter word instead of a five letter word in the main experimental block.

Oddball and Slow BCI conditions. The usual P300 BCI stimuli presentation rate (i.e., 5.3 flashes per second in the Standard and Inverted conditions in our study) is too fast for the visual oddball, where it would be associated with a too heavy load for the subject's vision and may be associated with an unacceptably low target detection performance. The stimuli presentation rate was, therefore, set to 1 stimulus per second in oddball, sufficient for a stable performance, and a Slow P300 BCI condition was introduced with the same stimuli presentation rate, to make the comparison of the ERP waveforms between oddball and BCI conditions more justified. The Slow BCI condition could be also useful for better characterizing the components of the ERP, as the non-overlapped waveforms can be obtained.

In the Oddball condition, the stimuli were the first six letters of Russian alphabet presented in the center of the black screen. One run consisted of presenting 20 sequences of 6 letters. Within a sequence, each letter appeared only once, and the order was random. No pauses were made between the sequences. Each letter was shown for 375 ms, with SOA of 1 sec. Before the run, the participant was told which letter (randomly chosen) should be attended. His/her task was to count silently the number of times this letter was presented. Four runs (two in the beginning of the experiment and two in the end) was made for each participant; thus, ERPs to 1 target x 20 sequences x 4 runs = 80 targets and to (6-1) non-targets x 20 sequences x 4 runs = 400 non-targets were collected per participant.

In the Slow BCI condition, most of the parameters were the same as in the Standard BCI condition, except the SOA and the stimulus duration, which were the same as in the Oddball condition, the number of flashing cycles set to 2, and the number of blocks of runs (i.e., the number of words) set to 4 (as for oddball, two in the beginning of the experiment and two in the end). This constituted 2 targets x 2 flashing cycles x 5 runs (letters) x 4 blocks = 80 targets and 10 targets x 2 flashing cycles x 5 runs (letters) x 4 blocks = 400 targets. Therefore, not only the temporal parameters were equal in Oddball and Slow BCI conditions, but the target/non-target ratio as well (1:5 in both conditions), which was important because the probability of target stimuli is the main factor determining the P300 amplitude in the oddball paradigm.

The order in which Oddball and Slow BCI conditions were presented was random. The order was counterbalanced across the participants. Each condition was preceded by a shorter practice run (in Oddball) or block of runs (in Slow BCI), organized in a way similar to Standard and Inverted conditions.

In addition, several other BCI related conditions were used for each participant. The description of these conditions and the results obtained with them will be published elsewhere.

2.3. *EEG acquisition*

EEG was obtained from 14 Ag/AgCl electrodes positioned at C3, Cz, C4, TP7, TP8, P7, P3, Pz, P4, P8, PO7, PO8, O1, O2 locations, with electrically joined reference at earlobes and ground at Fpz. These electrodes were fixed with a ribbon net adjusted for each participants individually in such a way that no pressure from it was felled during the whole experiment. Vertical EOG was recorded with bipolar electrodes placed above and below the left eye, and horizontal EOG was recorded with electrodes on the outer canthi. The EEG and EOG signals were bandpass filtered in the range 0.1-30 Hz with a notch filter at 50 Hz, amplified and sampled at 128 Hz by CONAN hardware.

2.4. *ERP analysis*

Signal processing and data analysis was made using MATLAB 7.1 (MathWorks). The EEG and EOG signal was converted into epochs, one epoch per each stimulus. Using EEGLAB, the epochs where $\pm 50 \mu V$ threshold was exceeded in any channel in the range -0.275..+0.525 sec relative to the flash onsets where marked automatically, and with subsequent visual screening they were rejected in the case of presence of artifacts; other epochs were also screened and were also rejected manually if contained strong EOG or EMG artifacts.

Then, the non-epoched EEG was filtered with 2nd order Butterworth filter in forward and backward direction (thus providing zero phase shift) in 0.5-20 Hz range, epochs were extracted again (-0.275..+0.525 s relative to the flash onsets) and those containing no significant artifacts (according to the above described screening of the nonfiltered epochs) were averaged for each subject and condition, separately for target and non-target flashes.

The amplitude of N1 peak in posterior locations (P7, P8, PO7, PO8, O1 and O2) was estimated as the minimum value in 125..275 ms time interval relative to the stimulus onset for the difference ERPs (target minus non-target) computed from averaged filtered waveforms. The difference curves were screened visually to check if the N1 peak indeed corresponded to this criterion. In three participants, the lower threshold was changed (no more than by 50 ms) to adapt to the individual ERP features while comparing Oddball vs. Slow BCI conditions; no changes were needed while comparing Standard vs. Inverted conditions. Wilcoxon matched pairs test was used for testing statistical hypotheses.

3. Results

As expected, ERPs in **Oddball and Slow BCI conditions** at posterior locations were very similar in the range of P300 wave (starting approximately from 250 ms), but highly different before it (Fig. 2). The detailed analysis of the difference between these conditions will be published elsewhere, but it is worth to mention here that the ERPs in Slow BCI conditions were, in general, similar to ERPs recorded in Standard condition discussed below, with the main difference related to appearing a kind of steady state response in the Standard condition, where the high stimulus presentation rate (ca. 5.3 Hz) lead to substantial overlap in the responses.

The grand averaged difference ERP are shown in Fig. 3. Only PO7 and O1 locations are shown to save space, however, other locations also demonstrated very little or almost no difference between the waveforms. Despite the huge difference in contrast and brightness of the stimuli, the size and the direction of brightness change, the shape and the amplitude of waveforms in Standard and Inverted conditions were very similar.

Statistical comparisons were made for the amplitude of N1 component in the difference waveforms (targets minus non-targets) at occipito-temporal and occipital locations P7, P8, PO7, PO8, O1, O2, in the following pairs of conditions: Oddball vs. Slow BCI, Oddball vs. Standard, Slow BCI vs. Standard, and Standard vs. Inverted. Significant differences were found only when Oddball was compared with the P300 BCI conditions, either Slow BCI or Standard (Fig. 4). In general, N1 amplitude in Oddball condition was much lower than in the P300 BCI conditions, while no difference was found between different BCI conditions; among them, Standard and

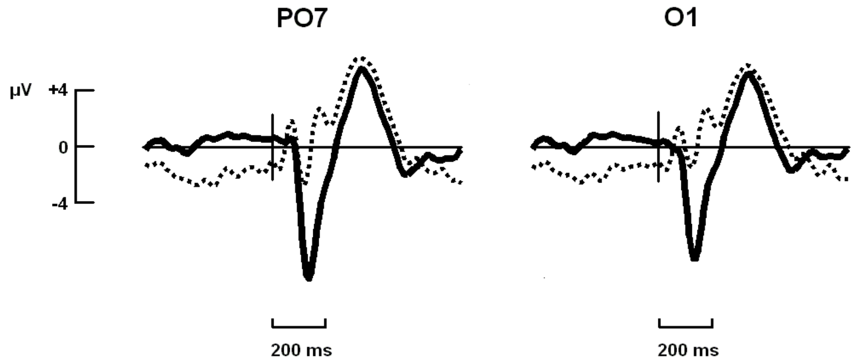

Fig. 2. Grand average (over the group of participants, n=10) ERP to targets for two electrode locations. Solid line, Slow BCI condition. Dotted line, Oddball condition. Vertical lines show the onset of stimuli.

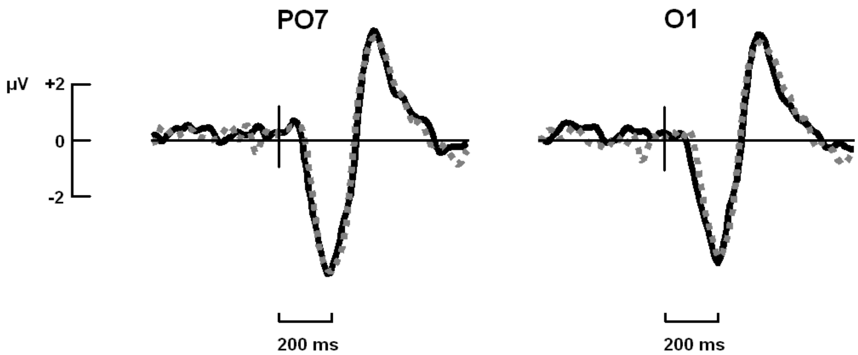

Fig. 3. Grand average (over the group of participants, n=10) difference ERP (targets minus non-targets) for two electrode locations. Solid line, Standard condition. Dotted line, 'Inverted' condition. Vertical lines show the onset of stimuli.

Inverted conditions were also not different.

4. Discussion

The main finding of this study was the luck of ERP change followed dramatically changed physical characteristics of stimuli in P300 BCI matrix. Not only P300 but also N1 component in the posterior visual areas was almost identical in grand averaged ERP for two conditions with completely different brightness and contrast, and with different direction and size of change of the brightness in the target area under the process of stimulation. While in Standard condition the "foveated" target

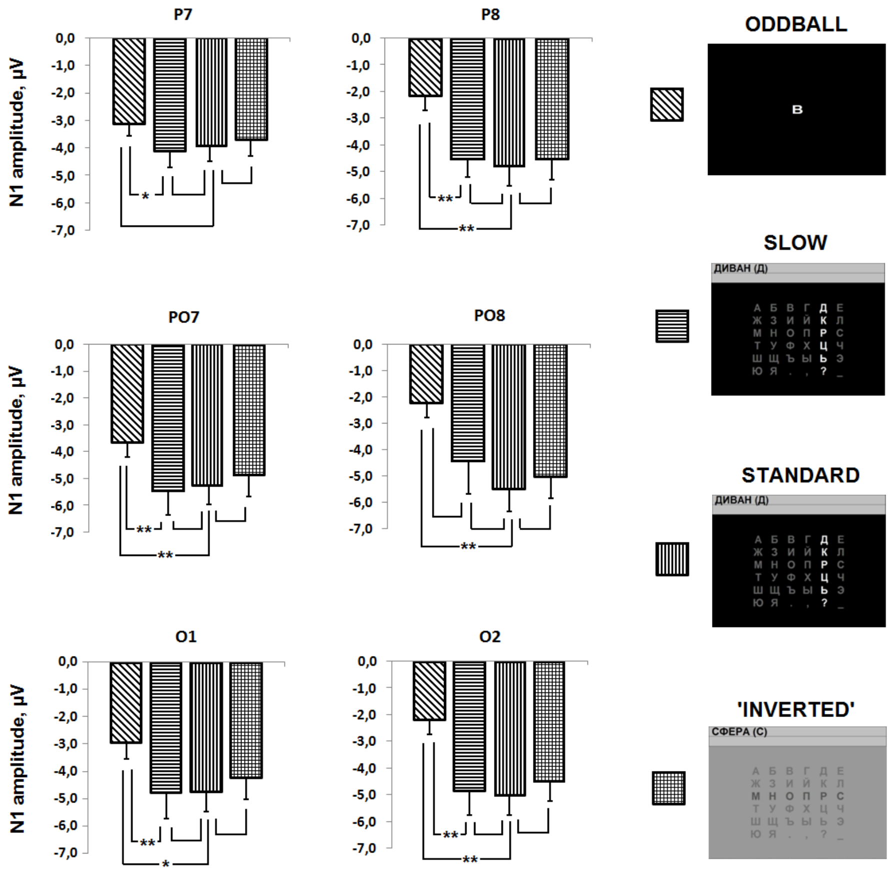

Fig. 4. N1 component group mean amplitudes and SEM (n=10) for difference ERP (targets minus non-targets) in four conditions at posterior electrode locations P7, P8, PO7, PO8, O1, O2. Wilcoxon mathed pairs test: * p< 0.05, ** p< 0.005.

provided much higher variations of the light energy received by the fovea comparing to non-target positions in the matrix, only small variations of the light energy evidently were possible in the Inverted condition. Thus, the high similarity between the difference (target minus non-targets) waveforms in these conditions excludes the explanation of N1 sensitivity to targets is based on "foveating" the targets.

The difference of N1 amplitude, and, more generally, of all the ERP interval before P300 between the Oddball and BCI conditions were, in contrast, very pronounced. As the "physical" nature of N1 variations has been ruled out by the "inverted" color scheme test, the most possible explanation of this component variations is its relation to spatial attention. This explanation should be checked more directly in further studies.

Our findings highlight the role of spatial factors in the P300 BCI paradigm, which probably should be best understood as a "position based BCI". A unique feature of the P300 BCI is that the user can choose, in one step, from a rather high number of commands, e.g., type a character selected from a set comprising the whole alphabet plus punctuation marks and digits. This is made possible due to attaching the commands to the simultaneously visible cells, whose positions are fixed in 2D space relative to each other. The spatial positions of the cells are mapped into time by flashing known rows and columns at known points in time, thus enabling deciphering the attended cell by analyzing temporally organized brain responses to the flashes. Both the high resolution of visuospatial attention and the ERP's high temporal resolution are nicely used together in the machinery of this BCI.

Importantly, during the stimulation the major task of user's visual system is only to maintain the fixation of attention and (though possibly less precisely) of the gaze on the selected location, and to detect the flashes at this location. There is no need to analyze in detail the content of the attended cell, as no change happens there other than flashes going on/off. Due to this, stable performance is possible even with a relatively high rate of flashing, not typical for visual oddball. For instance, Sellers et al. [22] presented flashes each 175 ms or each 350 ms and found even better information transfer rate in the case of shortest interstimulus intervals. One may hypothesize that the simplified task for the visual system in the P300 BCI paradigm and the very simple course of ERPs in the time interval before P300 (without clearly defined components other than N1, which could be associated with extensive processing of the details of visual images, as in the visual oddball paradigm) may be related to each other, but such a hypothesis clearly need more studies for justification.

Though the critical role of spatial attention in the Farwell and Donchin BCI paradigm have been little addressed in the course of the further development of this paradigm within the last 20 years, several attempts has been made recently to manipulate the features of stimuli, to ensure both well recognizable responses to targets and low fatigue and discomfort from the stimulation, at the same time. As we already mentioned, Salvaris and Sepulveda [20] compared BCI spelling in the "inverted" color scheme, similar to those used in our study but with much higher contrast and brightness variations, to the standard P300 BCI color scheme. They also tested some other stimuli variations. Takano et al. [25] studied green/blue stimulation. Hill et al. [6] proposed the use of flipping rectangles on which the letters in the matrix were superimposed, so that the flips are used instead of flashing. In all these studies, the new stimulation procedures were found to be superior to the standard stimulation. The fact found in our study, that even a very strong change of stimulation may not lead to changes in ERP, suggest that the BCI developers should not be constrained to relatively small modifications of the original Farwell and Donchin paradigm, but, instead, feel free to try to introduce any reasonable changes.

In a search for better organization of stimulation in the P300 BCI, Hong et al. [9] proposed a "motion-onset based" modification of this paradigm in a form of sophisticated paradigm including appearing colored bars below each character and their movement; the participant were asked to mentally name the color of the bar below the target character. Interestingly, they found an ERP component they called N200 with location and latency similar to N1 discussed in the current paper, which also well differentiated targets and non-targets. Though Hong et al. [9] considered this component as motion-specific one, it remains to be proven, from our point of view, that it is not related to the appearing of the stimuli bar, in which case it could be a manifestation of the same or similar mechanism as what is indexed by the N1 in usual P300 BCI paradigm. In any case, it makes sense to compare these components in the future studies.

The high dependence of the posterior N1 in the P300 BCI paradigm to targets and its independence of the stimuli physical characteristics means that it should be specifically addressed in BCI research and BCI development. First, efforts should be made to ensure large and stable target-related N1 variations. Further clarification of the mechanisms underlying this component in the P300 BCI paradigm is important for this. Secondly, BCI signal processing and pattern recognition techniques should be adjusted to employ both the P300 and N1 waves, to make possible for them to benefit from the combined use of these components which are rather different in latency, locations and other characteristics.

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