A P300 brain-computer interface with a reduced visual field

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Abstract

P300 brain-computer interface (BCI) is an experimental and clinical paradigm, where visual evoked potentials (VEPs) triggered by an attended stimulus are used to communicate users' messages to the outside world. In a typical implementation, called P300 speller, a subject looks at a display where text characters are flashing and attends to one of these characters. The attended character is detected as the one with the strongest VEP. Such a speller performs well when responses to the target and non-target stimuli are sufficiently different and, conversely, more trials are required for reliable selection when non-target stimuli cause sizeable VEPs. Although many strategies for improving the speller have been proposed over the years, a relatively simple one received little attention: reduction of visual field to diminish the contribution of non-target stimuli. To tackle this idea, we ran a pilot experiment in 10 subjects that first operated a traditional P300 speller and then wore an aperture that restricted their vision to the central field. Subjects selected text characters by looking at them. When the aperture was worn, responses to non-target stimuli were reduced in all subjects. Moreover, in 4 subjects, target-stimulus VEP changed in amplitude and/or shape. Since the aperture reduced the interference from non-targets and increased the response to target in a portion of cases, we suggest that this approach be used to improve BCI performance. In addition to the aperture usage, we argue that the removal of distractors could be achieved algorithmically. Additionally, future P300 BCIs utilize the different physiological properties of the central and peripheral visual fields. We also discuss how the proposed approach could provide insights on the mechanisms of visual processing.

Introduction

Following the introduction of P300 speller in 1988 by Farwell and Donchin (Farwell and Donchin 1988), myriads of studies strived to improve this method. The speller performance is hindered by the necessity to run many trials to distinguish target and non-target stimuli based on the comparison of the VEPs they evoke. Particularly, non-target items that are adjacent to the target object attract attention and interfere with the decoding performance (Fazel-Rezai 2007, Townsend, LaPallo et al. 2010). Several solutions to this problem have been explored, including randomly flashing stimuli instead of flashing rows and columns (Guger, Daban et al. 2009), rearranging the spatial configuration of simultaneously flashing stimuli (Townsend, LaPallo et al. 2010), suppressing the stimuli adjacent to targets during the calibration procedure (Frye, Hauser et al. 2011), and changing the characteristics of stimuli

(Salvaris and Sepulveda 2009, Jin, Allison et al. 2012). Yet, these approaches require a considerable amount of distracting stimuli, which slows the decoding and contributes to user fatigue (Boksem, Meijman et al. 2005, Käthner, Wriessnegger et al. 2014).

In this perspective, we discuss a straightforward way to reduce the interference from non-target stimuli, that is restricting vision to the central field. We describe our pilot experiments where visual field reduction was accomplished using an aperture. We observed that subjects wearing an aperture were able to perform the same task as they executed under the traditional P300-speller settings. Moreover, the aperture reduced the VEPs caused by non-target stimuli in all subjects and made more distinct the VEPs caused by the target stimuli in 4 out of 10 subjects. The increased contrast between the target and non-target stimuli could be used in the future to improve the speller performance.

We further argue that wearing a physical aperture is not the only way to reduce the interference from non-target stimuli. The same could be achieved algorithmically and/or using a hybrid BCI that incorporates eye tracking (Koo, Nam et al. 2014, Shishkin, Nuzhdin et al. 2016, Hong and Khan 2017). We suggest that the visual field reduction method could be useful for both clinical applications and studies of visual processing and attention.

P300 BCI with and without an aperture

As part of our ongoing experiments on P300 BCIs, we conducted a pilot study where healthy subjects first performed a traditional P300 task and then switched to wearing an aperture that restricted their sight to the central visual field (Figure 1).

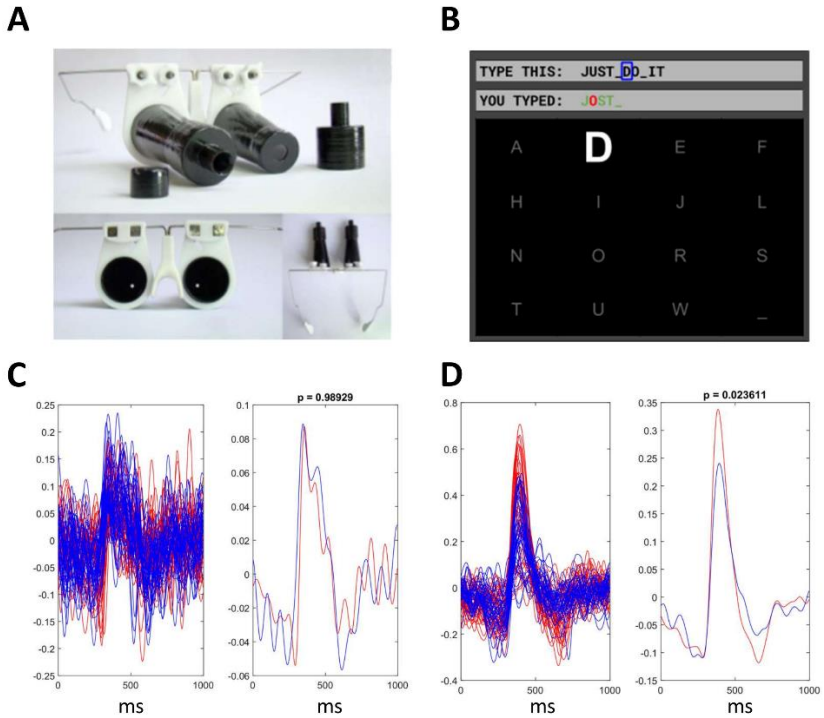

Figure 1. Experimental setup and example VEPs in response to target stimuli. A: Aperture headset. B: Computer screen with text characters in a 4 by 4 arrangement. C: VEPs in a subject with the response unchanged during wearing the aperture. Red lines correspond to the aperture condition, blue lines represent the no-aperture condition. Average VEPs for 10 flashes (i.e. one character spelled) are shown on the left, and average VEPs for all flashes (i.e. a complete phrase spelled) are shown on the right. D: VEPs in a subject with an enhanced response during the aperture condition.

The experimental procedure was approved by the research ethics committee of Samara State Medical University (protocol #204, December 11, 2019). All subjects gave informed consents to their participation in the study. Ten healthy subjects, all males, aged 19±0.0, right-handed, with right dominant eye determined with Miles test (Miles 1929), with visual acuity of 1.04±0.18 and 1.09±0.18 for the left and right eyes, respectively, measured with Huvitz CCP-3100 projector (HUVITZ Co., Ltd, S.Korea) using Cyrillic letters.

The experiments were conducted in a half-dimmed quiet room. Participants sat in front of a 40×70 cm computer monitor. The distance from the eyes to the screen was 80 cm. The BCI system incorporated an NVX-36 amplifier, NeoRec software (MKS, Russia), OpenViBE software (Renard, Lotte et al. 2010), VIBRAINT software, and an aperture headset (IT Universe Ltd). EEG channels P4, PZ, P4 were recorded according to the international "10-20" system. The left earlobe was used as the reference channel and the right earlobe as the ground. We used a textile cap with gel-based Ag/AgCl wired electrodes MCScap-E (MKS, Russia). The sampling rate of the NVX-36 amplifier amplifier was set to 250 Hz. The EEG signal from NVX-36 amplifier was received by OpenViBE Acquisition Server software and then transmitted to VIBRAINT software for processing. In the experiments with the aperture, the aperture headset was fixed to the head like regular glasses (Figure 1A). The aperture tubes were coated with an anti-glare spraying on the inside. The aperture opening was 5 mm in diameter. The distance from the openings to the eyes was 12 cm. Subject could see only one character at a time when wearing the aperture.

In our implementation of the P300 speller, 16 characters were displayed on a computer screen in a 4 by 4 arrangement (Figure 1B). The characters flashed randomly, one at a time. When flashing, the character doubled in size (i.e. linear dimensions), and its brightness increased by 80%. Flashes occurred every 110 ms (i.e. 9.1 Hz). Flash duration was 60 ms. Subjects used the BCI to generate a ten-character phrase ("JUST DO IT"), first with the traditional P300 speller and then while wearing the aperture. Prior to running each speller tasks, a calibration session was conducted, where data were collected needed for fitting an SVM-based classifier. The classifier was implemented in VIBRAINT software. Participants were instructed to look at the target character and avoid making head movements. For every character to be spelled, each screen item flashed 10 times. Next, the classifier predicted the target stimulus based on these data. The classification result was displayed on the screen. For example, in the experimental session shown in Figure 2B, the classifier correctly determined "J", "S", "T" and space, and confused "U" with "O".

The comparison of VEPs across the experimental conditions (with and without the aperture) was conducted offline. EEG signals were preprocessed for this analysis by applying a bandpass filtered in the range 1.0-15.0 Hz with a 4th order Butterworth IIR zero-phase filter. Additionally, EEGs on each channel were normalized to bring the amplitude to the [-1, 1] range. We used PZ channel to assess VEPs in different conditions.

Wearing the aperture resulted in a significant change of VEP in response to target stimulus ($p<0.05$ Wilcoxon rank-sum test for response amplitude) in 4 subjects out of 10, and no change in the rest of the subjects. Figure 1C shows the responses to target stimuli for a subject with no change in target-stimulus VEP occurring due to wearing the aperture. Blue lines correspond to regular P300 runs, and red lines correspond to the aperture condition. Traces shown in the left panel represent averages for 10 target flashes, and traces in the right panel represent averages for all flashes. In this case, VEPs are very similar in both conditions (Figure1C, right panel) and there is no statistically significant difference. Figure 1D shows the results for a subject with an approximately 40% increase in VEP amplitude when wearing the aperture; this effect is statistically significant.

Figure 2 shows VEPs (averages for all flashes) for both target stimuli (left parts of the panels) and non-target stimuli (right parts). Figure 2A and Figure 2C represent the same subjects as in Figure 1C and Figure 1D, respectively. In these examples, there is no significant change in the amplitude of VEP to target stimulus in two subjects (Figure 2A,B), and the response is stronger in the aperture condition in four subjects (Figure 2C-F). Moreover, in all cases there is a decrease in the response to non-target stimulus in the aperture condition. A particularly strong decrease in the non-target response is shown in Figure 2F. In this subject, cortical response was strong for both target and non-target stimuli during the regular P300-BCI runs, and the responses to non-target

stimuli were abolished by wearing the aperture. Overall, the aperture worked as designed. It diminished the responses to the interfering items, and in several subjects, target-stimulus VEP increased. These both effects enhanced the contrast between the target and non-target responses, which suggests that reducing the visual field to central vision could be useful to improve the performance of P300 speller.

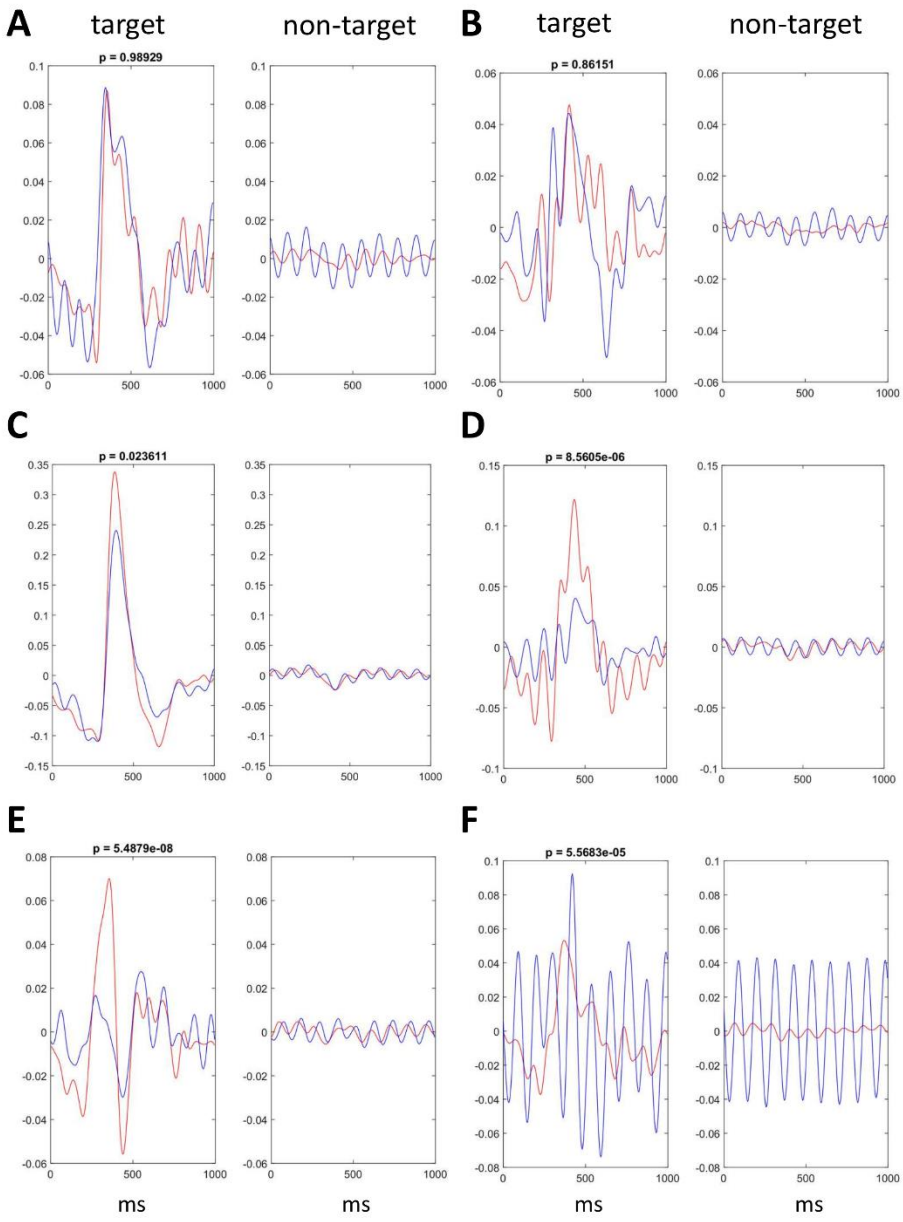

Figure 2. VEPs for target (left panels) and non-target (right panels) stimuli. Traces represent averages for all flashes. Blue lines are the responses for the regular P300 paradigm, and red lines are the responses for the aperture condition, where visual field was reduced to central vision. Panels A and C show the data for the same subjects as in Figure 1C and Figure 1D, respectively. There is no change in target-stimulus response in panels A and B whereas the other panels contain cases with such a change. In all cases, the response to non-targets decreased when subjects wore the aperture.

Discussion

Our pilot experiment showed that subjects could operate a P300 speller while wearing an aperture that restricted their visual field to central vision. With this method, the interference from non-target stimuli was reduced, as evident from VEP data. Moreover, in 4 subjects out of 10, we observed changes in cortical responses to target stimuli: in 3 subjects that was an increase in VEP amplitude and in one subject that was a replacement of a response to target highly contaminated by non-target responses by a clean response pattern. These preliminary observations support our hypothesis that removal of non-target stimuli (in this experiment, with the aperture) could improve the speller performance.

Our implementation of the reduced visual field idea could be improved in the future. Looking at the screen through a fixed-sized aperture is uncomfortable, and this problem could be tackled in the future using a variable-size aperture that narrows the visual field only when needed. Additionally, the same effect could be achieved with an algorithm that reduces the flicker of non-targets as VEP data accumulates and eventually stops it. A hybrid BCI that incorporates eye tracking (Koo, Nam et al. 2014, Shishkin, Nuzhdin et al. 2016, Hong and Khan 2017) could be also used for this purpose. Indeed, once the fixation point is detected, flashes of non-target items could be suppressed. With such a method, the BCI could be controlled without head movements, which were necessary in our implementation.

Regardless of the technical details of how our approach could be implemented, we see several advantages in using a speller where only the central visual field is used for stimulus delivery. The first advantage is that distractors do not interfere with selective spatial attention (Clark and Hillyard 1996, Hillyard and Anllo-Vento 1998, Luck, Woodman et al. 2000, Ordikhani-Seyedlar, Lebedev et al. 2016). This consideration is particularly important when the speller in patients who may have impaired attention in addition to the other neurological conditions (Vieregge, Wauschkuhn et al. 1999, Phukan, Pender et al. 2007, Nazhvani, Boostani et al. 2013, Yadav, Thiagarajan et al. 2014). The second advantage is the reduction of visual fatigue, which is a common problem for BCI spellers (Boksem, Meijman et al. 2005, Käthner, Wriessnegger et al. 2014). Finally, the third obvious advantage is that, when the number of non-target stimuli is reduced, the speller can work faster.

One could argue that, since we are suggesting not using non-target stimuli at all, the same could be achieved with an eye tracker and/or head-position tracker: once the gaze angle is reliably detected, spelling could be done without a BCI. While this solution could be practical in many cases, recording brain activity is still very useful (Shishkin, Nuzhdin et al. 2016) because it allows to better assess the subject's intention, level of attention, and the brain state. Additionally, eye/head tracking is not always possible. We suggest therefore that the most fruitful approach is using as many control signals as possible and selecting the most suitable ones for the concrete task (Hong and Khan 2017).

Even if the visual field reduction does not happen to be practical in some cases, it could be still useful for the assessment of individual subject's ability to control a BCI. For example, in our study, target-stimulus VEPs were unchanged for 6 subjects wearing the aperture, whereas they increased in 3 other subjects, which indicated that they could focus better on the target in the absence of distractors. Additionally, in one subject, responses to non-targets were extraordinarily strong in the regular P300-BCI sessions possibly because of the strong effect of the distractors on exogenous attention. The removal of distractors dramatically normalized the response to target stimulus. With more subjects tested in the future and the examination extended to patients, we expect that more useful information will be obtained regarding the effect of distractors on the BCI performance of different individuals. Even the simple aperture test implemented here could be useful as such a control.

In addition to improvements to BCI speller, the paradigm proposed here could be useful as a tool in research on brain mechanisms of visual processing and attention. Thus, it is well known that central and peripheral visual fields have different functional properties (Finlay 1982, Neville and Lawson 1987, Berencsi, Ishihara et al. 2005), but this topic has not been sufficiently studied with the BCI approach. Given that BCI research contributes to basic science

(Nicolelis and Lebedev 2009), we expect more fundamental insights on the brain mechanisms with the proposed approach.

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