A P300 BCI with Stimuli Presented on Moving Objects

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Abstract

In the P300 brain-computer interface, visual stimuli are presented at spatially fixed locations. Can this BCI work if the stimuli positions are allowed to move, e.g., when attached to different moving parts of robotic devices or to virtual objects in a video game? We designed a simple P300 BCI game with moving locations of stimuli and tested it in a four session experiment. Able-bodied participants played this game in either a single-trial (n=6) or a triple-trial (n=6) mode through all sessions. All of them performed better than randomly, and most of them maintained a high level of interest to the task up to the last sessions. Our study demonstrates that the P300 BCI can be extended to a version with moving stimuli positions.

1 Introduction

The P300 brain-computer interface (P300 BCI) provides a relatively high information transfer rate, while requiring no special training of the user and little time for classifier calibration. It currently appears to be the most commonly used BCI [1]. However, its static visual design pose limitations for possible applications. For example, in highly engaging video games moving elements usually play important roles. Creating an attractive game on the basis of a static "control panel" of the standard P300 BCI is a difficult task. Attaching the stimuli positions to the moving objects on which the player focuses his/her attention seems to be a much more prospective way to develop an engaging BCI controlled game. Control of prosthetic or robotic devices could be also more flexible if the BCI stimuli would be allowed to be presented at freely moving positions.

The use of moving objects as stimuli have been proposed in [2]. However, in this study the stimuli were presented at fixed positions. In our recent study [3] we demonstrated that brain event-related potentials (ERP) remain highly sensitive to the difference between the attended and not attended items when the P300 BCI stimuli matrix moves. A more radical solution is to make moving each stimulus position separately. We already found that the distance between stimuli positions in the P300 BCI matrix has little effect on the ERP difference between target and non-target stimuli [4], thus, the change of the distances during the motion unlikely can impair the BCI performance. Nevertheless, many other factors can, in principle, influence the P300 wave and the other ERP components important for discrimination of the brain responses [3], and an experimental proof is needed to confirm that the motion of the items on which the stimuli are presented would not prevent recognition of the user's commands.

In this paper, we describe preliminary results of testing a P300 BCI based game with stimuli presented on objects which *move on individual trajectories*.

2 Methods

Similarly to our previous (static) P300 BCI game, the BCI Puzzle [5], the goal of the player in the new game is to assemble a full picture from its fragments. The main difference is that in the new

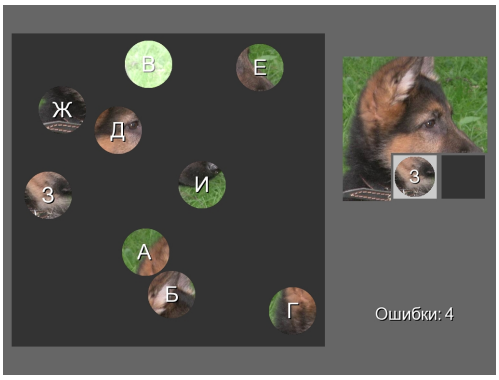

Figure 1: Example of the BCI game display. Each moving "ball" contains a fragment of the picture being assembled in the right. The correct order of targets is cued by letters (of Russian alphabet). A ball with letter "B" is "highlighted". In the bottom right, a counter shows the number of errors.

game each fragment is put into a ball moving on the computer screen (Figure 1). For research purposes, it was reasonable to simplify finding the current target (the ball to be pursued and attended): first, the balls were marked with the letters of Russian alphabet (all the participants were native Russian speakers) and the target order was always alphabetical; secondly, the current target was highlighted in a result panel where the puzzle was assembled.

12 healthy volunteers participated in four sessions on different days after signing the informed consent. Each session started from a calibration, and then the participants played, with short breaks, 10 games, each one with a new picture (a color photograph of an animal, plant or a car cut into 9 fragments). The fourth session consisted of only 5 games, as additional tests were done after the games (their results will be described elsewhere). In each run, after finding the target and preparing to attend the target stimuli, they pressed a mouse button, initiating start of the stimulation in 3 s.

For six participants (the single-trial group), each ball always flashed once, and the classifier was applied to single-trial EEG epochs related to each stimulus. For another six participants (the triple-trial group), three random "sequences" of flashes were given (each ball flashed three times in total), and the averages of three responses to stimuli related to each ball were used for classification. The player had to mentally note the flashes of the target item and pay no attention to flashing of all the other items.

If the ball classified as attended was the target ball, the related item in the picture in the result panel was filled, and the next to it became the new target. Otherwise, the error counter showed an increase by one and the target remained the same as in the previous run. "Winning" a game meant that all 9 fragments were identified as attended and the full picture was assembled. A game terminated before picture was assembled ("lost" game) if 10 errors was made in this game.

The ball size was 2°, the movement trajectories were linear (with natural change of direction after collisions), and the speed was 5°/s. They were presented on a CRT monitor at a distance about 85 cm from the eyes. A stimulus was an increase of brightness of a ball (see an example in Figure 1) for 125 ms. Balls flashed in a random order without pauses between the flashes. EEG was recorded at Cz, Pz, PO7, PO8, O1, O2 against a reference at the right earlobe, bandpass filtered in the range 1-10 Hz and decimated down to 20 Hz. A single EOG channel was also recorded. Each data epoch started from the stimulus onset and its length was 1 s. Channel data in each epoch were concatenated and formed a feature vector. Classifier weights were obtained with Fisher Linear Discriminant Analysis.

The participants rated their average interest to the task during the experiment by putting a mark on a Visual Analog Scales (VAS) in the end of the session (0 corresponded to "not interesting" and 100 to "extremely interesting"). The scales for different sessions were positioned on the same sheet one below another. This was done to allow and to encourage the participants to use the

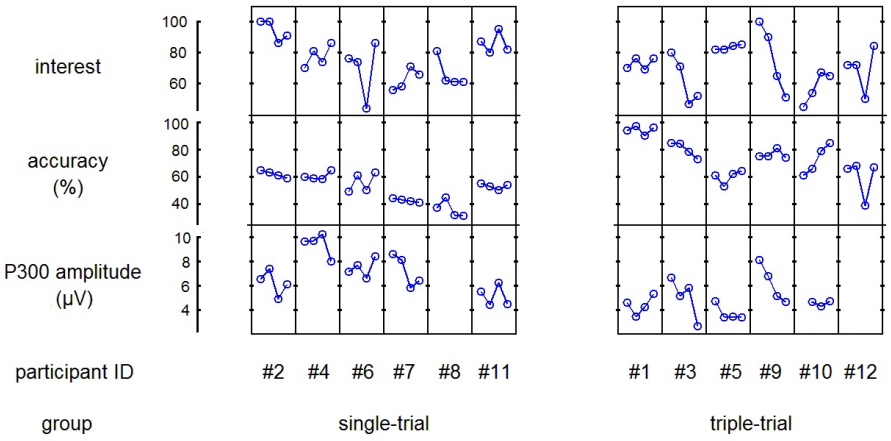

Figure 2: Self-estimated interest to task during the session, BCI accuracy and the P300 amplitude at Pz in each participant.

previous estimates as a basis for finding a position for the new estimate in relation to them.

In the offline analysis, the P300 amplitude was measured at Pz after filtering the signal in 0.5-20 Hz band and ERP averaging, as the maximum value in the 250-500 ms interval relative to the stimulus onset. In a few cases, the P300 amplitude could not be estimated: two participants did not have a clear P300 (instead, a positive wave with latency around 200 ms was present in responses to targets); same applied to one more participant but only in his first session. Only few epochs (2% of all epochs, on average) contained EOG artifacts; these epochs were excluded from analysis. It seemed that strong artifacts from saccades were not common in our data, as attending the moving object required only smooth pursuit eye movement and small saccades. Blinking artifacts were also rarely found, probably because the stimulation periods were short.

3 Results

Interest to task, accuracy and P300 amplitude data per participant and session are shown in Figure 2.

Interest to task in single-trial group was 78(15) (M(SD)) in the first session and 79(12) in the last one. In triple-trial group, group averaged interest values failed from 75(18) in the first session to 69(15). 2-way MANOVA showed no significant effects for factors Session, Group and for their interaction.

In triple-trial group, participant's *online accuracy* per session ranged from 39% to 97%, and for single-trial, from 31% to 65%. Thus, all subjects in all sessions performed better than at the random level, which was 11% (as one of 9 items should be chosen in each run). According to 2-way MANOVA (Group x Session), the triple-trial group demonstrated higher accuracy than the single-trial group ($F(1,10) = 10.8$, $p = 0.008$). However, no dependence on session was revealed in both groups.

P300 amplitude at Pz was higher in the single-trial group than in the triple-trial group and showed a tendency to decline across the sessions: effect of Group was significant ($F(1,7)=6.0$, $p=0.04$), effect of Session was marginally significant (Wilk's lambda $=0.25$, $F(3,5)=4.9$, $p=0.06$) and the interaction between Session and Group factors was not significant (Wilk's lambda $=0.33$, $F(3,5)=3.4$, $p=0.11$).

Small group sizes and variations in individual dynamics across sessions (Figure 2) do not allow a detailed analysis of the relations between the studied variables. In fact, positive intra-individual correlations, especially between interest to task and the P300 amplitude, were high (in participants

#9 and #11, Pearson correlation coefficient was 0.98), but negative correlations were also observed (especially high for #7, for whom it was -0.99). The highest correlations could be, however, a result of trends existing in both variables (participants #7, #9) and appear just by chance in the rest of cases (e.g., in #11).

4 Discussion

In this paper, a P300 BCI modification with stimuli presented on moving object was described for the first time, to the best of our knowledge. Such modification could, in principle, negatively affect the performance of the BCI, for example, because of attention distracting effects from stimuli presented on objects moving around the target object and even colliding with it. However, the accuracy obtained in this study with a simple classifier was already sufficient for playing a game and for maintaining high interest to task during all four sessions even in a group using the single-trial mode of BCI operating.

The results obtained in this preliminary study are already encouraging for the application of the P300 BCI to games for healthy players, who can easily pursue the moving targets by gaze. In heavily paralyzed persons, gaze control is often impaired, and additional studies are needed to determine if it is possible to operate the P300 BCI with moving positions of stimuli without pursuing the stimuli by gaze.

5 Conclusion

This study demonstrated that the P300 BCI can operate efficiently when stimuli are presented on moving positions.

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