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Fixation-related potentials: Foveal versus parafoveal target identification

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Abstract

The P300 event-related potential (ERP) can be used to infer whether an observer is looking at a target or not. Common practice in P300 BCIs and experiments is that observers are asked to fixate their eyes while stimuli are presented. First studies have shown that it is also possible to distinguish between target and non-target fixations on the basis of single ERPs in the case that eye movements are made, and ERPs are synchronized to fixations (fixation-related potentials or FRPs) rather than to stimulus onset. However, in these studies small object sizes ensured that participants could only identify whether the object was a target or non-target after fixating on it. We here compare (non-)target FRPs when objects are identified before versus after fixation. We also examine ERPs from static eyes conditions. FRP shapes are in accordance with the notion that the late component of the P300 is associated with identifying a target, and eye movements do not substantially affect the P300. Even when the time of object identification is unknown, it is possible to distinguish between target and non-target FRPs on a single FRP basis. These results are important for fundamental science and for developing applications to covertly monitor observers' interests.

1 Introduction

The P300 event related potential (ERP) occurs 300-500 ms after a stimulus has been presented that draws attention, either through bottom-up mechanism as in odd-ball paradigms or through conscious guidance, as made use of in P300 BCIs. In P300 experiments and BCI paradigms, participants are usually asked not to move their eyes around the time that the P300 is expected to occur, in order to avoid eye movement artefacts in the EEG. It is however expected that the same kinds of processes and ERPs occur when observers actively sample their visual environment themselves by making eye movements. In this case, one would need to examine the EEG traces relative to self-paced fixation onset (fixation-related potential, or FRP). There are only few studies that demonstrate that fixation-related P300s are elicited by top-down determined target identification (Kamienkowski et al., 2012; Brouwer et al., 2013). These studies control for potentially confounding factors that (may) differ systematically between target and non-target fixations, such as fixation duration, preceding saccade length and low-level visual properties of the objects of interest. Brouwer et al. (2013) showed that target and non-target FRPs could be distinguished above chance on a single FRP level. In the

experiments by Kamienkowski et al. and Brouwer et al., small object size ensured that participants could only identify the object (target or non-target) after fixating it. However, in real life, targets can also be identified parafoveally ('in the corner of the eyes'), prior to fixation on the target. ERP experiments in which participants fixated a fixation cross demonstrated that target stimuli presented in the periphery also elicit P300s. We expect P300 FRPs to occur earlier when targets are identified before than after fixation. In the current study, we examine FRPs when a target has been identified before fixating it (large target) and after (small target). We also include a condition in which the eyes do not move in order to examine whether planning (or inhibiting) a saccade affects the P300 latency and amplitude. Our main interest is in whether we can still distinguish between targets and non-targets at a single FRP level in the case that time of target identification relative to fixation is unknown. This would be required if one is interested in monitoring the interest of naturally behaving observers.

2 Methods

EEG-electrodes were placed at Fz, Pz, Cz, POz, Oz, P3, P4, PO7 and PO8 with a ground electrode at FPz. The EEG electrodes were referenced to linked mastoid electrodes. Four electrodes were used for EOG recording: two at the outer canthi left and right; one above and one below the left eye. Both horizontal and vertical EOG-electrodes were referenced to each other. Data were recorded at 256 Hz and filtered online using a 0.1 Hz high-pass, a 100 Hz low-pass and a 50 Hz notch filter.

Stimuli were shown on a 20" tft-screen with a refresh rate of 60 Hz and at a viewing distance of 60 cm. They were circular patches with a black center and white surround, or the other way around. One type was designated as target, the other as non-target. Center and surround had an equally sized surface area. They were shown against a gray background in one of four locations (top-left, top-right, bottom-left, or bottom-right) at 12° of visual angle from a fixation cross, located in the center. The stimuli were sized either 4° or 0.25° in diameter, so that only the large stimuli could be identified when gaze was at the fixation cross, whereas an eye movement was required for the small stimuli. All patches were surrounded by a black square frame which had thickness of two pixels, allowing the participants to easily detect the location of the (small) stimulus.

Twelve observers participated. During the task, the fixation cross was present continuously. One after the other, the stimuli were presented for 1000 ms in one of the four corners (random order) with an inter-stimulus interval of 750 ms. The participants were asked to count targets. After every 21 trials, the participant indicated the number of counted targets through the keyboard.

There were three conditions: one in which participants were asked to keep fixating the cross and that contained only large stimuli (static-large); one in which they were asked to make an eye movement to the stimulus as soon as it appeared that contained only large stimuli (saccade-large); and the same one but with small stimuli (saccade-small). Each condition contained 336 trials, 112 of which were target presentations. Targets and non-targets were presented in random order. Trials from the two saccade conditions were presented in random order within one saccade block. Half of the participants started with the saccade block, the other with the static fixation block. Type of target (black center or white center) was also counterbalanced within these two participant groups.

To determine fixation onset in the saccade condition, we detected the peak EOG eye movement speed after stimulus onset and set eye fixation onset at the end of the saccade related peak. For some analyses, we identified and removed eye movement artefacts from the EEG using ICA (Jung et al., 2000). Independent components that reflected EM activity were selected manually by comparing components with the original EOG data. For eleven participants the first two components and for one the first three components were identified to reflect EM and removed from the original data.

For each participant, we estimated whether ERPs (running from stimulus onset until 500 ms later) and FRPs (from fixation onset until 500 ms later) could be correctly classified as associated with a

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target or non-target. These estimates were produced using a five-fold cross-validation procedure. We used the same classification pipeline as described in Brouwer et al. (2013). In short, an L2-regularized logistic regression classifier was trained on (9 electrodes * 129 samples) 1161 dimensional feature vectors. All adjustable parameters were optimized independently of the test sets. The classification procedure was performed on 8 different sets of data as indicated in Table 1. For ERPs, we determined classification performance for data from the static large condition. For FRPs, we determined classification performance for data from the two saccade conditions separately as well as together. All sets of data were examined with and without eye movement artifacts removed. We used Equal Error Rate as a measure of classification performance since this measure is independent of the percentage of misses (targets classified as non-targets) and false alarms (non-targets classified as targets). It reflects the proportion of errors for the case that the percentage of false alarms and misses are equal.

3 Results

Figure 1 shows the average target- and non-target ERPs and FRPs in the most relevant comparison conditions for electrode POz (where effects tended to be clearest, consistent with Brouwer et al., 2013), after removing the eye movement artefacts. The shaded areas represent p-values lower than 0.01 (dark) or 0.05 (light) as indicated by paired sample t-tests performed on every time sample of target and non-target values. As expected, ERPs (i.e. stimulus locked traces) and especially the target minus non-target difference trace are similar, regardless of eye movements being made. Also as expected, the difference peak of FRPs (i.e., fixation locked traces) occurs earlier when objects could be identified in the periphery (large object) compared to when not (small objects).

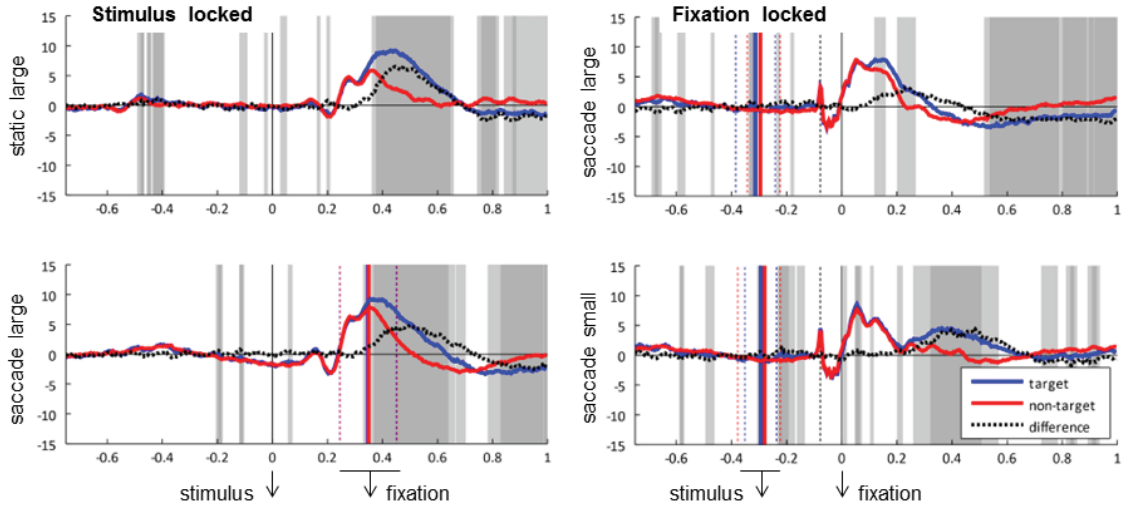

Figure 1: ERPs (left) and FRPs (right) for target (blue) and non-target (red) traces in different conditions, averaged over participants for electrode POz. Dotted curves indicate the difference wave.

Table 1 shows the results of the ERP and FRP classification analysis, separately for each condition, for the two saccade conditions grouped, and both with and without eye movement artefacts removed. Single trial classification is possible above chance in all cases as indicated by Wilcoxon signed rank tests on 0.5 (chance level) minus Equal Error Rates per participant (all eight p-values <0.01). On average, the lowest error rates are achieved when eyes are static and EEG traces are locked to stimulus onset, while the highest error rates are observed for the most difficult case, i.e. traces

locked to fixation onset and unknown time of object identification (large and small stimuli mixed). Removing eye movement artefacts does not increase error rate, confirming the idea that distinction between targets and non-targets is based on brain rather than eye signals.

		Eye artefacts removed	Raw traces
Stim locked	Static large	0.29±0.06 [0.20-0.39]	0.29±0.06 [0.21-0.38]
Fix locked	Sacc large	0.35±0.08 [0.15-0.42]	0.35±0.06 [0.23-0.43]
	Sacc small	0.31±0.06 [0.17-0.38]	0.40±0.05 [0.30-0.48]
	Sacc small & large	0.37±0.06 [0.19-0.44]	0.41±0.04 [0.32-0.46]

Table 1: Equal Error Rates averaged across participants ± the standard deviation. Between brackets are the minimum and maximum Equal Error Rates as observed across participants. Chance level is at 0.5.

4 Discussion

We found that we can still distinguish between target and non-target FRPs in the case that time of target identification relative to fixation is unknown. This is important when one is interested to use FRPs to monitor an observer's interest since for most visual exploration tasks, time of target identification is unknown. Equal Error Rates may seem high at first sight in comparison to other P300 studies. However, one has to note that these results reflect single trial classification and are based on data with a relatively large proportion of targets which is expected to result in relatively low P300 amplitudes.

Since attention and eye movements are intimately connected (Kowler, 2011) one might have expected that planning or inhibiting saccades would interfere with P300 latency and amplitude. However, we found that the static-large and saccade-large FRPs are very similar.

As expected, when objects are identified before fixation, the FRP P300 difference peak between targets and non-targets occurs earlier compared to identification after fixation. The FRPs in the saccade-small condition nicely reflect parafoveal and foveal visual processing. The first peak (after a peak that corresponds with a presaccadic spike potential) is similar for target and non-target traces, as well as for the traces in the saccadic-large condition. This peak probably reflects the detection of a relevant visual event in the periphery, i.e. stimulus onset. Then, there is a peak only for targets which is delayed in the case of small target size since targets can only be identified after an eye movement has been executed. The target trace of saccade-small may show us the P3a and P3b (Polich, 2007) more separated in time than is usually the case in experimental settings.

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