 DOI:10.3217/978-3-85125-260-6-65

Distinguishing Between Target and Non-Target Fixations in a Visual Search Task Using Fixation-Related Potentials

A.-M. Brouwer[1], J. Vincent[1,2], M. A. J. van Gerven[3], J. B. F. van Erp[1]
[1]TNO, Soesterberg, the Netherlands; [2]University College Utrecht, the Netherlands;
[3]Donders Institute, Nijmegen, the Netherlands

Correspondence: A.-M. Brouwer, TNO Perceptual and Cognitive Systems, Kampweg 5, 3769 ZG Soesterberg, the Netherlands.
E-mail: anne-marie.brouwer@tno.nl

Abstract. The P300 can be used to infer whether an observer is looking at a target or not. Common practice in P300 experiments and applications is that observers are asked to fixate their eyes while stimuli are presented. We investigated the possibility to differentiate between target and non-target fixations in a target search task involving eye movements by using EEG epochs synchronized to fixation onset (fixation-related potentials: FRPs). Participants systematically scanned search displays consisting of six small Landolt Cs in search of Cs with a particular orientation. After each search display, they indicated whether and where target Cs had been presented. As expected, an FRP component consistent with the P300 reliably distinguished between target and non-target fixations. For 8 out of 11 participants, it was possible to classify single FRPs into target and non-target FRPs above chance (62-77% correct). These results are the first step to practical applications such as covertly monitoring observers' interests and supporting search tasks.

Keywords: EEG, eye movement, P300, fixation-related potential, visual search

1. Introduction

The P300 is an event related potential (ERP) occurring approximately 250-500 ms after a target or task-relevant stimulus has been presented. Because the P300 is relatively easy to detect and its amplitude depends on voluntarily controlled attentional processes, it is often used as a control signal in Brain-Computer Interfaces. In P300 BCIs different stimuli are sequentially presented. The stimulus chosen by the observer, i.e., the stimulus that the observer focuses his/her attention on, elicits a P300 that is detected by the computer. Usually, participants using a P300 BCI or taking part in an experiment in which the P300 is investigated are asked not to move their eyes around the time that the P300 occurs. For example, they fixate a fixation cross that is subsequently replaced by a particular visual stimulus, or they fixate a target amongst non-targets and count the number of times it is flashed. However, in natural visual search tasks observers sample their visual environment by self-initiated fixations and saccades instead of fixating a location where the visual stimulus is known to appear. We suspect that the brain's electrophysiological response to perceiving a target amongst non-targets will be similar regardless of whether the eyes are static and targets and non-targets are presented at a fixation location or whether an observer fixates a set of non-targets individually in search for a target. Here we try to infer from EEG whether individuals look at a target object or not in situations with natural eye movements. Rather than locking EEG to stimulus onset, we lock EEG to fixation onset and examine whether we can distinguish target from non-target fixations on a single-fixation basis. If so, this would enable new types of (online) applications like covertly monitoring observers' interests and supporting search tasks as well as more ecologically valid scenarios in EEG studies about visual search, selective attention and detection. Fixation-related potentials (FRPs) have been studied before. However, existing studies look at earlier components than the P300 or differences between target and non-target FRPs may be due to confounding factors. Also, we are not aware of a study that looked at single FRP classification.

2. Material and Methods

Thirteen participants took part in the experiment. In each of four blocks they searched 60 search displays for a target C. A search display consisted of 6 Landolt Cs with four possible orientations: the gap could be at the top, the bottom, left or right. The Cs were arranged in a circle and displayed at the 12, 2, 4, 6, 8 and 10 o'clock positions. It was impossible to detect the orientation of any C other than the one currently fixated. The target C could have any orientation, but remained the same for each individual participant. The non-target Cs had randomly selected other

orientations. One third of the displays contained 2 targets, one third 1 target and one third no targets so that participants could (almost) never know whether the next C would be a target. Participants were instructed to fixate on each C, starting at the C at the 12 o'clock position and switching to the next in clockwise direction as fast as they wished. When the participants were done, they indicated whether and where they saw the target C.

Eye position was recorded at 50 Hz using a Tobii x50 eye tracker. EEG was recorded at Fz, Cz, Pz, Oz, P3, P4, PO7 and PO8. EOG electrodes were fitted to the outer canthi of both eyes, as well as above and below the left eye. Using the Tobii data we selected fixations on the C's at the 2, 4, 6, 8 and 10 o'clock positions. Subsequently, EOG was used to define fixation onset that was exactly synchronized with EEG. FRPs were defined as EEG samples starting at fixation onset and ending 500 ms after. Only the first fixation on a particular C was included in the analysis. Since in this study we are interested in clean data reflecting the P300, FRPs associated with fixations shorter than 500 ms were discarded. For three participants, this resulted in less than 10 valid target fixations. These participants were therefore excluded from analysis. For classification, data were balanced by selecting random subsets of FRPs such that they contained an equal number of targets and non-targets. The raw time series for eight channels were standardized to have mean zero and unit standard deviation and used as input to a linear support vector machine. For each participant it was estimated whether FRPs could be correctly classified as associated with a target or non-target. These estimates were produced using a ten-fold cross-validation procedure. For each participant and electrode, we also calculated grand average target and non-target FRPs. These served as input for running paired sample t-tests that were used to test for significant differences between target and non-target FRPs (alpha of 0.01). In addition, we checked for significant differences in the 100 ms epoch before fixation onset to verify that FRPs do not differ before fixation onset. To verify that EOG associated with target and non-targets does not systematically differ as intended by our experimental design, we examined EOG 'FRPs' associated with the same set of fixations as used in the FRP analyses in the same way.

3. Results

Grand average target and non-target FRPs are consistent with a higher P300 for a target than for a non-target fixation. The difference is significant at some frames towards the end at the parietal and parieto-occipital electrode sites. Except for one frame at PO8, the 100 ms epoch before fixation onset does not show differences between targets and non-targets confirming that identification of the C happened only after fixation onset. T-tests on the EOG 'FRPs' and the 100 ms before did not indicate significant differences between targets and non-targets, confirming that saccades to targets and non-targets were similar. All 11 participants included in the analysis have average classification accuracies over 56%. For 8 participants, classification performance was significantly higher than chance level ($p < 0.05$) and for one participant, performance is on the verge of significance ($p = 0.05$). The range of classification accuracies for participants with successful classification is between 62 and 77%, with a mean of 70%.

4. Discussion

In the current study we provided evidence for a target-linked P300 in a well-controlled search task involving eye movements, where ERPs were locked to fixation onset rather than to the onset of an externally imposed stimulus. We showed that individual FRPs can be labeled offline as belonging to a target or non-target fixation for most observers with 70% certainty on average. Our findings show that also for later components it is possible to investigate ERPs in contexts with self-paced eye movements and suggest that P300 knowledge that has been gathered within tasks with stationary eyes could be generalized to situations with eye movements. Furthermore, our findings are of relevance in applied fields of research such as passive Brain-Computer Interfaces, augmented cognition and neuroergonomics. While augmented cognition and passive BCI focus on online use of brain signals, offline use of brain signals that reflect the state of the user could also be useful when for instance evaluating different interfaces or studying task performance over time. Remaining questions that we would like to answer mostly relate to the application of FRPs. While the current experiment was designed to investigate FRPs in a controlled manner, for practical applications we need to examine situations that resemble the case that the use of FRPs is envisioned for. One important aspect is the general fixation duration in those situations. In the current setting, we lost a large amount of data because of the < 500 ms exclusion criterion. However, in our restricted search task fixation durations were relatively short. Also, we demonstrated in a later experiment that when targets can be detected in the periphery, i.e. before the target is fixated, the positive target potential occurs close to fixation onset. In this case fixations with shorter durations may also be used to extract FRPs.