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Early and late selection processes have separable influences on the neural substrates of attention

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ABSTRACT

To improve our understanding of the mechanisms of target selection, we examined how the spatial separation of salient items and their similarity to a pre-defined target interact using lateralised electrophysiological correlates of visual spatial attention (N2pc component) and visual short-term memory (VSTM; SPCN component). Using these features of target selection, we sought to expand on previous work proposing a model of early and late selection, where the N2pc is suggested to reflect the selection probability of visual stimuli (Aubin and Jolicoeur, 2016). The authors suggested that early-selection processes could be enhanced when items are adjacent. In the present work, the stimuli were short oriented lines, all of which were grey except for two that were blue and hence salient. A decrease in N2pc amplitude with decreasing spatial separation between salient items was observed. The N2pc increased in amplitude with increasing similarity of salient distractors to the target template, but only in target-absent trials. There was no interaction between these two factors, suggesting that separable attentional mechanisms influenced the N2pc. The findings suggest that selection is initially based on easily-distinguished attributes (i.e., both blue items) followed by a later identification-based process (if necessary), which depends on feature similarity to a target template. For the SPCN component, the results were in line with previous work: for target-present trials, an increase in similarity of salient distractors was associated with an increase in SPCN amplitude, suggesting more information was maintained in VSTM. In sum, results suggest there is a need for further inspection of salient distractors when they are similar to the target, increasing the need for focal attention, demonstrated by an increase in N2pc amplitude, followed by a higher probability of transfer to VSTM, demonstrated by an increase in SPCN amplitude.

1. Introduction

The visual system must often deal with more information than can be processed effectively, and neural selection mechanisms are required to distinguish relevant from irrelevant stimuli within the rich influx of visual stimulation. Many researchers have proposed that attention somehow biases limited capacity mechanisms towards stimuli that are the most relevant for the current task (e.g., Bundesen, 1990). An electroencephalographic event-related potential (ERP) component known as the N2pc has been associated with the deployment of visual spatial attention. This component is characterised by a contralateral negative deflection at posterior electrodes to the attended visual field relative to ipsilateral electrodes. The N2pc is typically observed between approximately 180–300 ms post-stimulus onset (e.g., Luck and Hillyard, 1994a) and likely reflects neural activity involved in target selection and processing, and perhaps distractor suppression (Eimer, 1996; Luck and Hillyard, 1994a, 1994b). The degree to which this ERP component is modulated by either top-down or bottom-up processing during target selection as well as the precise underlying mechanisms are still debated. Indeed, there is a lack in consensus with respect to the mechanisms underlying N2pc activity, and thus it continues to be under active study (see Luck and Kappenman, 2011, for a review). The aim of the present work was to understand better the N2pc by examining how two aspects of target selection influence this component. These two aspects were the spatial separation of salient items within the visual field and their similarity to a pre-defined target template. We wished to determine if manipulations targeting these aspects of selection would interact, or produce additive results on the amplitude of N2pc.

Evidence from N2pc research suggests that the deployment of visual spatial attention is strongly influenced by stimuli possessing task-

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relevant features (e.g., Kiss et al., 2008; Luck and Hillyard, 1994a; Luck and Hillyard, 1994b; Eimer and Kiss, 2008; Leblanc et al., 2008; Eimer, 1996). Indeed, the N2pc component was shown to be modulated by target-distractor similarity in a contingent capture paradigm (Leblanc et al., 2008). In their second experiment, Leblanc et al. (2008) used a rapid serial visual presentation (RSVP) and had participants search for a target (a colour-defined letter or digit) embedded in a stream of non-target items of the same category as the target (letters or digits) but differing in colour. Capture was induced by presenting peripheral distractors along with the digit or letter preceding the target. Distractors matching the target category (e.g., a digit distractor when searching for a digit target) elicited a larger N2pc component relative to distractors that did not match the target category (e.g., a letter distractor when searching for a digit target), but only when the distractors possessed the target-defining feature (i.e., same colour). In other words, when attention was captured by this target defining feature (here colour), the N2pc was enhanced. Furthermore, using an attentional capture task, Kiss et al. (2008) demonstrated that the N2pc is influenced by task instruction. The N2pc component was larger for target stimuli, and was reliably present (although attenuated) when nontarget stimuli possessed target defining characteristics (e.g., the same colour or shape). In contrast, the N2pc was absent when the dimension shared by both the target and the colour singleton was not task-relevant. Their results reinforce those of Leblanc et al. (2008), also suggesting that a stimulus possessing target defining features influences the deployment of visual spatial attention during target selection. These electrophysiological results (Leblanc et al., 2008; Kiss et al., 2008) support the contingent involuntary orienting hypothesis of Folk et al. (1992), who provided strong behavioural evidence suggesting that attentional resources are involuntarily allocated to stimuli possessing characteristics shared with a pre-defined target (see also Ghorashi et al., 2003).

The N2pc component is also influenced by the physical placement of potentially relevant items within the visual field (Hilimire et al., 2009; Hilimire et al., 2010). Hilimire et al. (2009, 2010) demonstrated that the spatial proximity of two task-relevant salient items (both items were salient by virtue of their colour difference with grey non-salient items, where one was green and the other orange) modulated the N2pc component, even when the distance gave no information about target identification. Participants were instructed to indicate the orientation of a green or orange target (the letter T) while ignoring the salient distractor of the opposite colour (either green or orange) present among non-salient grey distractors. Subjects did not know the colour of the target at the beginning of the trial, and so presumably had to be ready to process either or both coloured items. The stimuli formed a circle around fixation and thus all had the same distance from fixation. With an increase in spatial proximity between two salient items there was a decrease in N2pc amplitude. The authors suggested that the presence of salient objects near the target caused competition and mutual suppression, and that the attended region shrinks until only one object is finally selected. These results are in line with the biased competition model, where both targets and non-targets are said to be competing for representation and that competition is biased towards information pertinent to the current task set (Desimone and Duncan, 1995).

In the present study, we examined the relationship between salient distractor similarity to the target template and the physical distance separating two salient items in visual search using the N2pc as an electrophysiological index of visual spatial attention. Our experiment was in part motivated by previous research (Aubin and Jolicoeur, 2016) examining different stages in target selection and how these affect the N2pc component. Aubin and Jolicoeur (2016) conducted three experiments in which two salient items (either two salient distractors or a target and a salient distractor) were presented with 14 non-salient grey items on an invisible circle around fixation. Salient items were either in adjacent positions or separated by three grey non-salient distractors. The target item was a vowel whereas salient distractors could be consonants (high semantic similarity to the target), digits (medium semantic similarity to the target), or non-alphanumeric characters (low semantic similarity target). Small variations were made in the three experiments: (1) in addition to semantic categories, non-alphanumerical characters also varied on a physical level (they possessed distinct features); (2) non-alphanumerical characters varied only on a semantic level (they possessed similar features to the other semantic categories); and (3) one salient item was blue and the other red (the colour of the salient items was irrelevant for target selection). In all three experiments, subjects were presented with six consecutive frames (multiple frame procedure; MFP), where each frame contained a target and a salient distractor or two salient distractors, and instructed to report the total number of targets (vowels) they counted at the end of the presentation sequence (i.e., after the sixth frame).

When non-alphanumerical characters were physically distinct (Experiment 1), a reduced N2pc was observed, but only when salient items were in adjacent positions. When this physical disparity was eliminated (Experiment 2), the distance separating salient items no longer interacted with distractor category. Finally, the authors examined whether distractor suppression was facilitated by having a distractor differing on a task irrelevant low-level feature level (Experiment 3). If low-level feature dimensions (here, colour) affected the N2pc post-target selection (because it is task irrelevant), the component would be attenuated when salient items were presented in close proximity and differed in colour compared with when they did not. However, the N2pc was not modulated by distractor category and the spatial distance effect remained. The authors concluded that, in Experiment 1, the physically distinct non-alphanumeric characters could be suppressed in an earlier stage of selection when they were in adjacent positions, attenuating the N2pc. However, when items are not physically distinct, processing continued to a second identification-based stage of selection (Experiment 2). The authors therefore proposed a model in which an early-selection filter first compares the salient items to the target template, and if items can be rejected on the basis of low-level features, the probability of their selection to move onto later stages of processing is decreased, resulting in a smaller N2pc amplitude. They suggested that early selection is therefore based on distinctive shape features, and that these items are more easily rejected when they are closer together.

The present work sought to expand on the model of early and late selection proposed by Aubin and Jolicoeur (2016). We were interested in examining whether their non-alphanumeric characters in Experiment 1 were more easily identified as distractors when salient items were adjacent, as demonstrated by a reduced N2pc, because they possessed an additional discontinuous feature, whereas all other salient items used in their paradigm (the other distractor groups and targets) were composed of similar features. More specifically, the non-alphanumeric characters used by Aubin and Jolicoeur (2016) contained small closed square regions within their characters that made them distinct from all other stimuli. For this reason, in the present study, we used salient distractors that differed from the target stimuli on a continuum. Our stimuli varied in similarity along a single simple dimension: line segment orientation. Participants searched for either a horizontal or vertical blue line segment (target) among oblique line segments, one of which was blue (salient distractor) and the rest were grey. The blue salient distractor deviated from the target orientation in a graded fashion. This was achieved by using distractors that were oblique line segments deviating by 22.5°, 45°, or 67.5° from the target orientation. In this way, we could vary distractor-target similarity in a graded fashion, along a single dimension. The spatial distance separating the salient items (either two salient distractors or a target and a salient distractor) was also manipulated: salient items were either in adjacent positions or separated by three non-salient distractors. Finally, targets were either present or absent. In target-absent trials, two blue salient distractors were presented. If the interaction observed by Aubin and Jolicoeur (2016) was due to a distinct feature possessed by the non-alphanumerical characters, that is, the small closed square, then in our