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The effect of modulating top-down attention deployment on the N2pc/PCN

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ABSTRACT

The N2pc (PCN) component of the event-related potential (ERP) waveform provides a useful tool for directly assessing the locus of spatial attention in visual search. It is still unclear whether the amplitude of the N2pc/PCN relates to the deployment of attentional resources. A key issue is the lack of evidence that top-down allocation of attention affects the N2pc/PCN amplitude. Previous findings could be explained if manipulating different expectancy strategies changes participants' search mode, causing them to redefine the target's features. In this study, we explored the relationship between N2pc/PCN amplitude and top-down attention allocation by manipulating the discriminative difficulty (differences in the response-defining feature) but leaving the search difficulty (target's saliency) unchanged. Using the same sets of stimuli, in a blocked condition, participants showed the expected higher amplitude of N2pc/PCN in the hardest condition, compared to easier discrimination conditions. Importantly, there was no difference in the N2pc/PCN when the exact same stimulus sets were presented in a randomly interleaved mixed set. At a behavioral level, in both conditions performance was significantly slower for the hardest condition. This finding indicates that the N2pc/PCN component is modulated by the predictability of discriminative difficulty, which reflects the modulation of top-down attentional deployment.

1. Introduction

In electrophysiological studies of human visual search, the most common approach has been to compute event-related potentials (ERPs) that are time-locked to the onset of search displays. The N2pc (N2-posterior-contralateral) or PCN (Posterior-Contralateral Negativity) is an ERP component that displays an increased negativity over posterior scalp areas contralateral to an attended stimulus. It is observed between 180 and 300 ms after display onset, and is assumed to reflect the allocation of attention to the location of the target (Eimer, 1996; Hopf, 2000; Luck & Hillyard, 1994a, 1994b; Töllner, Müller, & Zehetleitner, 2012; Woodman & Luck, 1999). Understanding the nature of the N2pc/PCN is vitally important, since it is becoming an increasingly popular tool in investigations of attention allocation in different tasks (Couperus & Quirk, 2015; Eimer & Grubert, 2014; Eimer & Kiss, 2007; Li et al., 2012; Liu et al., 2009; Nako, Wu, Smith, & Eimer, 2014; Zhao et al., 2011). Numerous studies of N2pc amplitude have sought to clarify what type of attentional selection mechanisms are reflected by this component and what can affect it. Early investigations linked the N2pc to the process of suppressing irrelevant distractor stimuli, in the context of target identification (Luck & Hillyard, 1994b). This led to the hypothesis that the N2pc would be elicited whenever irrelevant distracters were presented with a target. However, Eimer (1996) found that a robust N2pc was also observed when only one non-target item was presented in the hemifield opposite to the target. Eimer proposed that the N2pc relates to the selection of task-relevant stimuli. Thus it remains an open question what exactly the amplitude of N2pc reflects during visual search tasks.

One conjecture is that N2pc amplitude might be mediated by the deployment of attentional resources, which constrain what resources are employed for cognitive performance. There is ample evidence that the deployment of attention can be driven either by bottom-up or top-down mechanisms (Buschman & Miller, 2007; Kastner & Ungerleider, 2000). In this regard, N2pc amplitude may also be modulated by bottom-up or top-down attention allocation. Indeed, there is evidence that N2pc amplitude can be modulated by bottom-up attention allocation during visual search (Hickey, McDonald, & Theeuwes, 2006; Töllner, Zehetleitner, Gramann, & Müller, 2011; Zhao et al., 2011). For instance, a study by Töllner

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et al. (2011) explored how visual saliency affects the processing of singleton feature targets. Participants were asked to search for the singleton target among distractors. The singleton target was defined either by color or by orientation. The target-distracter similarity was manipulated with three different feature contrast levels for both color and orientation. They found that N2pc amplitude was highly correlated with the degree of saliency between the target and distractors, indicating a bottom-up modulation of N2pc amplitude. A similar result was observed in Zhao et al. (2011), in which N2pc amplitude was affected by the physical disparity between target and distractors.

The effect of top-down attention allocation on N2pc amplitude has also been confirmed by previous studies (Eimer & Kiss, 2008; Kiss, Jolicœur, Dell'Acqua, & Eimer, 2008; Kiss, Van Velzen, & Eimer, 2008; Leblanc, Prime, & Jolicoeur, 2008; Schankin & Wascher, 2008). These studies found that different expectancy strategies for a target affect the amplitude of the N2pc (Kiss & Eimer, 2011; Töllner, Conci, & Müller, 2015; Töllner, Zehetleitner, Gramann, & Müller, 2011). For example, Kiss and Eimer (2011) using a cueing paradigm found that when two color singletons were defined as the target (in experiment 1), both target-color singleton cue and irrelevant-color singleton cue could capture attention and elicit an N2pc effect. However, when one of the two color singletons was defined as the target and the other was defined as non-target (in experiment 2), no cue validity effect or N2pc effect was found for the non-target-color singleton and irrelevant-color singleton. However, all these studies manipulated different expectancy strategies to change participants' search mode and this resulted in a consequent change of participants' definition of target features. Changing the definition of the target's features induced a change in the target's salience relative to distractors. That, in turn, led to a discrepancy in the N2pc amplitude. In this regard, most previous studies manipulated top-down strategies to modulate the target's saliency among surrounding distractors, so consequent changes in N2pc could result from a top-down modulation of stimulus-driven processes. Thus, we cannot directly conclude that the N2pc amplitude was associated with top-down changes in attention allocation.

One effective way to explore the relationship between N2pc amplitude and top-down attention allocation is to manipulate the task difficulty while the target's saliency remains unchanged using a target discrimination task. Zhao et al. (2011) used a visual search and discrimination task to investigate the effects of physical disparity between target and distractors and thus the effect of discrimination difficulty on the N2pc component. Participants were asked to search for a color singleton as the target and then discriminate which part of the cross-like target's vertical bar was shorter (the response-defining feature). In the task, the definitions of the target depended on the relationship between target and distractors while the discriminative difficulty was related to the difference in the response-defining feature of the target. Thus the discriminative difficulty does not affect bottom-up attention allocation irrespective of the definition of the target's feature. By manipulating the discriminative difficulty of the target, they predicted that once attention was attracted to the locus of the selected target, more attentional resources would be allocated to it in the hard discrimination condition and thus a larger N2pc component should be elicited compared to the easy condition. However, the experiment found no evidence of a relationship between the N2pc amplitude and discriminative difficulty. If N2pc amplitude reflects the deployment of attentional resources, then the pattern of N2pc amplitude should relate to the discriminative difficulty of the target as the physical disparity between the target and the distractors changes, because the discriminative difficulty might also modulate the deployment of attentional resources. It is noteworthy that, in that experiment, the hard and easy discrimination conditions were presented randomly and with equal probability within each block. Participants could therefore not predict which kind of condition would be in the next trial. Thus, it is possible that participants adopted the same attention allocation strategy regardless of the level of discriminative difficulty in each condition and allocated equal resources to different levels of discriminative difficulty.

The present study was designed to test the attentional resource assumption that top-down attention allocation could modulate N2pc amplitude. In the visual search and discrimination task, participants were asked to find the target and to differentiate the target's vertical bar. Thus, the discrimination difficulty was determined by the response-defining feature, irrespective of target's saliency. Since the unpredictability of trials might have prevented previous participants from using different attention allocation strategies for hard vs. easy discrimination conditions, in the present study one task presented hard and easy discrimination trials in blocked conditions, and the other in a randomly mixed condition. The order in which the two tasks were delivered was counterbalanced across participants. We hypothesized that the amplitude of the N2pc would be modulated in blocked conditions compared to mixed condition.

2. Methods

2.1. Participants

Fourteen undergraduates (4 of them male; mean age = 23 years; range, 20–25 years) participated in the experiment as paid volunteers. All subjects were right-handed, Chinese native speakers with normal or corrected-normal vision, and none had a history of neurological or psychiatric disorders, color blindness or visual field defects. One participant was excluded because of an excessive error rate (>40%), and one further participant was excluded due to over-long reaction times.

2.2. Stimuli

The stimuli were presented on a 17- inch CRT monitor at a viewing distance of 70 cm. A central black fixation cross was visible on screen throughout the experiment. Search displays consisted of 8 cross-like objects, presented at equidistant positions from central fixation (4.5° visual angle) along the circumference of virtual circle centered on the fixation point. In each trial seven distractors and one target item were presented in the virtual circle, with the target item always appearing in either left visual field (LVF) or right visual field (RVF). The top part of the vertical bar was randomly either shorter or longer than the bottom part in the 8 cross-like items (See Fig. 1).

The colors of the stimulus items were manipulated in CIE L*u*v* color space, with all colors being independent of the luminance. All the distracters were the same color with RGB values: 0, 169, 139 and CIE Luv values: 61.86, −50.883, 14.026. The target had RGB values: 0, 166, 171 and CIE Luv values: 61.837, −47.300, 14.55.

Trials were set at one of three different levels in the response-defining feature (discriminative difficulties). In the hard discrimination condition (CH), the top part of the vertical bar was either 10% shorter than the bottom part or vice versa. In the medium discrimination condition (CM), the top part of the vertical bar was either 20% shorter than the bottom part or vice versa. In the easy discrimination condition (CE), it was either 30% shorter than the bottom part or vice versa.

2.3. Procedure

Participants were seated in a dimly lit and soundproofed room and given instructions describing the task. There were two parts to