Biological Psychology 125 (2017) 28–35

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Research Paper

Differential engagement of attention and visual working memory in the representation and evaluation of the number of relevant targets and their spatial relations: Evidence from the N2pc and SPCN

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ARTICLE INFO

Article history:
Received 10 May 2016
Received in revised form 20 January 2017
Accepted 23 January 2017
Available online 27 January 2017

Keywords:
Attention
Visual working memory
VWM
N2pc
SPCN
ERP

ABSTRACT

We examined the role of attention and visual working memory in the evaluation of the number of target stimuli as well as their relative spatial position using the N2pc and the SPCN. Participants performed two tasks: a simple counting task in which they had to determine if a visual display contained one or two coloured items among grey fillers and one in which they had to identify a specific relation between two coloured items. The same stimuli were used for both tasks. Each task was designed to permit an easier evaluation of either the same-coloured or differently-coloured stimuli. We predicted a greater involvement of attention and visual working memory for more difficult stimulus-task pairings. The results confirmed these predictions and suggest that visuospatial configurations that require more time to evaluate induce a greater (and presumably longer) involvement of attention and visual working memory.

1. Introduction

We are frequently exposed to numerous incoming stimuli that can overload recognition and memory mechanisms (Sperling, 1960). As such, the ability to select the most relevant stimuli to be processed to a higher level is a critical aspect of normal cognitive function. Selective attention and the cognitive functions associated with it have been studied extensively over the years using chronometric methods complemented by measures of brain activity (Pashler, 1988). Event-related potential (ERP) studies have found specific patterns of brain electric activity that are associated with spatial attention and visual working memory, two cognitive functions critical for this type of processing. These components, measured using well-established methods, are now easily reproducible making them an efficient way to study the evolution of sensory and cognition operations over time under different experimental conditions. Here we will focus on two components, the negativity 2 posterior contralateral (N2pc) and the sustained contralatedal negativity (SPCN).

The N2pc (Luck & Hillyard, 1994) is a lateralized component characterized by an enhanced negativity at occipital sites contralateral to the visual hemifield where a relevant item is presented and where attention is presumed to be engaged. The N2pc usually peaks between 200 and 280 ms post-target onset and is usually maximal in amplitude near electrodes PO7 and PO8. It appears to originate in lateral portions of the visual extrastriate cortex (Hopf et al., 2000). There is solid evidence that the N2pc reflects neuronal activity related to attentional selection, although the exact underlying mechanisms are still under debate. Many researchers consider the N2pc as a moment-to-moment index of visuo-spatial attention. Some evidence suggests that the amplitude of N2pc reflects the number of distinct representations that are selected and individuated for further processing (Mazza & Caramazza, 2011). The N2pc has been used to track the deployment of visual spatial attention in a number of situations (e.g., as a reflection of attentional capture, Brisson, Leblanc, & Jolicoeur, 2009; Hickey, McDonald, & Theeuwes, 2006; Kiss & Eimer, 2011; Leblanc, Prime, & Jolicoeur, 2008).

The amplitude of the N2pc has been shown to depend on the nature of the attentional processing required by the task. For example, Mazza and Caramazza (2011) asked subjects to perform three

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http://dx.doi.org/10.1016/j.biopsycho.2017.01.011
0301-0511/

different tasks using the same set of stimuli (red and green diamonds on a black background). In one task they reported the number of stimuli presented in a particular colour (e.g., how many red items were in the display?); in another task they reported whether the display contained stimuli in a specific colour, regardless of their number; and in a third task they reported whether a specific number of coloured stimuli are present or not (e.g., were there exactly 2 red items?). Their results showed a modulation of the amplitude of the N2pc for target number (how many items) for the first and third tasks, but not for the second one. The authors took these results to suggest that a coarse initial representation of the relevant objects is created to permit the individuation of each of them by the visual system; a task-dependent process that can be affected by top-down influence. In their view, N2pc reflects the individuation process.

The SPCN (Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006) is also a lateralized component seen at occipital sites contralateral to the presentation of encoded stimuli. The SPCN is also called the contralateral negative slow wave (CNSW, Klaver, Talsma, Wijers, Heinze, & Mulder, 1999), or contralateral delay activity (CDA, Vogel & Machizawa, 2004). It is a later component with an onset usually after 300 ms post-target with a maximum also often at the PO7 and PO8 electrodes. The duration (hence offset) of the SPCN has been shown to depend on the duration of processing of information held in visual working memory, either by virtue of the duration of a retention interval (e.g., Perron et al., 2009) or by the duration the processing of information held in visual working memory (e.g., Prime & Jolicoeur, 2010). The SPCN has been linked to active maintenance of information in visual working memory in experiments in which the amplitude of the SPCN increased as the number of items held in memory increased. Importantly, this increase reached a ceiling or plateau when the number of items corresponded to the maximum capacity of the subjects in the experiment (Robitaille et al., 2010; Vogel & Machizawa, 2004). Passage into visual working memory appears to be spontaneously required when a task requires detailed form discrimination for patterns that are not highly overlearned (e.g., Kiss & Eimer, 2011). The SPCN has also been shown to be functionally dissociable from the N2pc, despite very similar scalp distributions of voltage fields (e.g., Jolicoeur, Brisson, & Robitaille, 2008). The SPCN has also been observed in tasks in which the stimuli are continuously visible, as in the curve-tracing task (Lefebvre, Jolicoeur, & Dell'Acqua, 2010). Still, much work remains to be done to understand the exact functional correlates of the N2pc and the SPCN, and of their interrelations.

Experiments on visuospatial attention and working memory are typically based on experiments in which each trial involves the presentation of one visual array used by the subject to base an immediate response. We will call this approach the single-frame procedure. In the present work we used a multiple frame procedure (MFP), in which each trial involved the presentation of six frames followed by the subject's response. The response was based on how many times a specific target was presented in the preceding set of six frames. This procedure takes advantage of the high temporal resolution of electroencephalography (EEG) and the fact that EEG can be used to monitor sensory, perceptual, and cognitive process as they unfold even in the absence of an overt response (see Bentin et al., 2007 for an example). The MFP allows us to multiply the number of events we are able to present to the participants while keeping the length of the study similar to one conducted with a single frame procedure. The activity we are interested in occurs shortly after the presentation of each frame, and the MFP in conjunction with EEG recordings, allowed us to examine attentional, visual working memory, and downstream cognitive operations more efficiently than with single-frame methods (see Sagiv & Bentin, 1999; Vogel & Luck, 2000; for other examples of procedures based on target counting). The MFP was used in previous work, to study colour-specific effects on attentional deployment, or conceptual and physical similarity of targets and distractors, with a focus on the N2pc component, providing strong support for the method (Aubin & Jolicoeur, 2016; Drisdelle, Aubin, & Jolicoeur, 2017; Pomerleau, Fortier-Gauthier, Corriveau, Del'Acqua, & Jolicoeur, 2014).

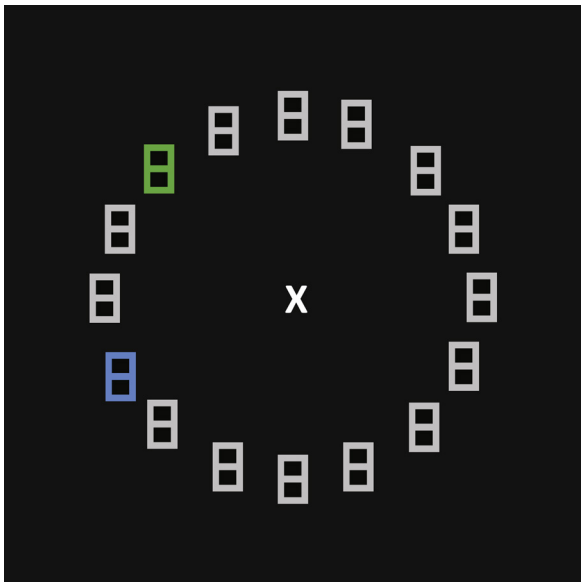

Fig. 1. Example a stimulus display in a frame with two coloured items. (For interpretation of the references to colour in the text, the reader is referred to the web version of this article.)

The main goal of the present research was to examine the role of attention and visual working memory in the processing of simple visual displays requiring either to evaluate the number of target stimuli in the display or to verify a simple spatial relation among them. We used a MFP and EEG recordings to study the underlying mechanisms mediating performance in these tasks and in particular we relied on the SPCN to track the involvement of the visual working memory for different stimulus configurations within specific cognitive tasks.

Our hypothesis was that visual working memory would be involved to a greater degree when a given stimulus-task pairing would require more processing, compared with a stimulus-task pairing with a lighter processing demand. We expected a smaller SPCN for lighter loads. Our strategy was to combine identical stimulus configurations with two different tasks in such way that one configuration would produce a heavier load in one task and a lighter load in the other task, whereas a second configuration would produce the opposite pattern. We explain the rationale for these predictions in the remainder of the Introduction.

One task required determining how many salient visual stimuli were in a visual display. This task was based on the one used by Mazza and Caramazza (2011), which we called 'Count' (C) in this article. Using displays like the one in Fig. 1, we included either one coloured item (either green or blue) or two coloured items (two green, two blue, or one green and one blue). In the context of the MFP, subjects performed one block of trials in which a target was defined as a display containing a single coloured item, regardless of colour. In a second block of trials, a target was defined as a display containing two coloured items, regardless of colour. Subjects reported how many targets (displays matching the target definition) were seen after viewing a set of six displays. We expected to replicate the findings of Mazza and Caramazza (2011), concerning the difference between displays containing one versus two items, namely a larger N2pc and SPCN for displays with two items, regardless of target definition (one vs. two). More importantly for our