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Backward masking interrupts spatial attention, slows downstream processing, and limits conscious perception

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ABSTRACT

The attentional blink (AB) is a difficulty in correctly processing a target when it follows one or more other targets after a short delay. When no backward mask is presented after the last critical target, there is no or little behavioral AB deficit. The mask plays an important role in limiting conscious access to target information. In this electrophysiological study, we tested the impact of masking on the deployment and engagement of attention by measuring the N2pc and P3 components in an RSVP paradigm. We found that the presence of a mask in an AB paradigm reduced the amplitude of the N2pc, P3a, and P3b components. In addition to reducing encoding in memory, masking also reduced the effectiveness of the deployment and engagement of attention on the last target. We discuss the role of these findings in the context of current masking, consciousness, and AB models.

1. Introduction

Visual information processing has been studied extensively over several decades by pushing the systems implicated in this processing to their limits. The rapid serial visual presentation (RSVP) paradigm has proven useful to determine the temporal limits of visual processing (Potter & Levy, 1969). RSVP involves a sequence of stimuli usually presented at the same spatial location one after the other, each one for a brief period of time (e.g., 100 ms). It was discovered in 1987 (Broadbent & Broadbent, 1987; Weichselgartner & Sperling, 1987) that when subjects are asked to report two targets (T1 and T2) among distractors (D), separated by a 200–500 ms lag (e.g., D, D, D, T1, D, D, T2, D), the accuracy of report for the second target is lower compared to when it is presented later relative to the first target (e.g., D, D, D, T1, D, D, D, D, D, D, T2, D). This phenomenon gathered a lot of interest through the years from scientist seeking to understand capacity limitations in the information processing system and the correlates of consciousness. The cause of this deficit, termed attentional blink (AB; Raymond, Shapiro, & Arnell, 1992), has yet to be fully understood, despite a wide range of empirical papers on the subject and a growing number of proposed models (see Dux & Marois, 2009; Martens & Wyble, 2010, for reviews).

A number of factors have been found to influence the AB, one of which is the backward masking caused by the distractor following T2, which we will call T2 + 1. Masking is defined as the reduction in visibility of a stimulus (target) by a spatially or temporally close second stimulus (mask) (Bachmann, 1984; Breitmeyer & Öğmen, 2006). Giesbrecht and Di Lollo (1998) found that

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when the RSVP in an AB paradigm ended with the last target instead of an additional distractor (a mask), no behavioral AB occurred; accuracy for the last target was at ceiling. Later work showed that an AB can be found even when the last target is not masked as well as when distractors are replaced by blank intervals, but it is invariably smaller in amplitude compared with the AB found with a trailing mask (c.f., Arnell & Jolicœur, 1999; Nieuwenstein, Potter, & Theeuwes, 2009; Ptito, Arnell, Jolicœur, & Macleod, 2008). In the present work, we will use a backward noise mask designed to make more difficult the processing of both the shape of the target to be reported, as well as its color. The latter was important because color was the attribute used to determine which stimulus (among two) was relevant for the task. Although manipulations of masking have been used a number of times in the AB paradigm to study how processing unfolds over time, less is known about how masking affects the deployment of visual spatial attention in this paradigm. Masking is often assumed to erase the visual information from the target or to interrupt its processing, although theories which are seeking to explain masking are more complex and more nuanced (Breitmeyer & Öğmen, 2000). In general, a better understanding of the role of masking on the deployment of attention in AB would be desirable.

Here we recorded the electroencephalogram (EEG) and used the event-related potential method (ERP) to deepen our knowledge of how masking the last target in an RSVP stream affects the temporal dynamics of attention and other mechanisms involved in the processing of said target from stimulus input to representations that are amenable to conscious access. Our goal was to isolate ERP components associated with a precise cognitive process from the complex stream of processing stages mediating performance in the AB paradigm. We measured ERPs elicited by the last target in an AB paradigm and compared them between lag 3 (short delay between the last and penultimate targets) and lag 8 (long delay between the targets) trials and between trials in which the last target was either masked or not masked.

Vogel and Luck (2002) were among the first to study the impact of masking on ERP components in the AB. The P3b component yielded interesting results. This component is typically observed at mid-parietal electrode sites (i.e., Pz) and is thought to reflect working memory encoding (Fabiani & Donchin, 1995; Polich, 2007). As in previous studies, they found an almost completely suppressed P3b during the AB for masked trials at short lags (e.g., Vogel, Luck, & Shapiro, 1998). When T2 was not-masked however, the P3b component was not suppressed in terms of amplitude, but the onset of the P3b was delayed at lag 3 compared to lag 7 despite accuracy levels suggesting no AB (Vogel et al., 1998; see also Sessa, Luria, Verleger, & Dell'Acqua, 2007). These findings were particularly important because they suggested that the absence of an AB effect on accuracy of report of T2 could not be interpreted as an absence of AB interference on the processing of T2. The delay of the P3b provided strong evidence for either an interruption or a slowing of encoding of T2 resulting from concurrent processing of T1 (see Jolicoeur & Dell'Acqua, 1998). This important finding was replicated in other studies (e.g., Dell'Acqua et al., 2015; Ptito et al., 2008). Vogel et al. (1998) argued that the perceptual representation of T2 could be sustained for a relatively long period of time if it was not followed by another item (see also; Jolicœur, 1999a). This representation was therefore still available when the encoding of T1 was completed, allowing subsequent but delayed processing of T2. If a mask (a distractor) followed T2, however, its perceptual representation was lost and/or overwritten by the subsequent stimulus before encoding processes devoted to T1 were available for T2. This made the last target unavailable for conscious report. Interestingly, Jolicoeur and Dell'Acqua (1998) reported several experiments in which visual stimuli that had to be encoded for later report (at the end of each trial) were followed by a second stimulus that required an immediate speeded response. Response times increased as the delay between these two stimuli was reduced. This finding suggested that encoding visual stimuli for later report was sufficient to delay or slow the processing of trailing stimuli (see also Jolicœur, Dell'Acqua, & Crebolder, 2001). The delay of P3b onset at short lag in the AB is consistent with the increases in response time reported by Jolicoeur and Dell'Acqua (1998) or Jolicœur et al. (2001; see also Dell'Acqua, Jolicœur, Vespignani, & Toffanin, 2005; Jolicœur, 1999b).

If we assume that the P3b component reflects the process of encoding information into a general working memory system, then the results described briefly in the foregoing passages suggest that encoding T1 in the AB paradigm slows or postpones one or more operations prior to, or at, the passage of information into working memory. According to locus-of-slack logic (e.g., Pashler & Johnston, 1989), results reported in Jolicœur et al. (2001) suggested that effects of the contrast of T2 on response times were underadditive with decreasing SOA between T1 and T2, suggesting in turn that very early sensory processing of T2 takes place before—and is therefore not affected by—capacity limitations causing the AB (see Jolicœur et al., 2001, for a discussion of the locus-of-slack logic on the context of the AB). Furthermore, Vogel et al. (1998) found no effects of AB on the visual P1 component, also suggesting a locus of interference somewhere after early sensory encoding and at or before encoding into working memory. In the present study we will examine effects of masking to determine if components after the P1 but before the P3b might be affected during the AB. Finding such effects would suggest a locus of interference prior to the one reflected by the P3b (in addition to an effect on the P3b), while finding no other effects on earlier ERP components, would provide empirical support that the principal locus of AB interference would be at encoding in working memory.

One component worthy of examination in this context is the P3a. This more anterior component, preceding the P3b, is hypothesized to reflect stimulus-driven frontal attentional engagement on targets (Polich, 2007). There are several models of AB interference but they do not all agree on the role attentional engagement plays in the deficit. Chun and Potter's (1995) two-stage model, for example, proposes that only one target at a time can be consolidated in memory. Any subsequent target therefore has to wait until the first target is fully encoded before having access to the encoding stage. Meanwhile, if a second target is too close in time to the previous target, the perceptual trace of the second one fades (or is overwritten) before it can be encoded. It is not clear, in this model, what role attention might play. Dell'Acqua et al. (2015) however, did find a lag effect on P3a amplitude to T2 when T2 was not masked, suggesting a link between attentional engagement and the AB deficit. Consistent with this finding, many models put attentional mechanisms at the forefront of their model. For example, the episodic simultaneous type, serial token model (Wyble, Bowman, & Nieuwenstein, 2009) holds that activation of a target is enhanced by attentional mechanisms. Accordingly, the attentional blink deficit takes place because attention inhibits trailing distractors during the encoding of the first target. If the