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Change is good: Inter-trial switching of target category improves attentional selection in time

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ABSTRACT

Limitations in the rate at which our attention can sample rapidly presented visual events are reflected in the attentional blink (AB), the inability to successfully report the second of two target stimuli embedded among distractors when separated by a temporal interval of approximately 300 ms. In two experiments we tested for predictions of two accounts of AB that ascribe the phenomenon to a temporary loss of attentional control or to an overzealous application of attentional control over the input filter. Manipulating the control load during the rapid serial presentation of visual events by means of a cued attentional switching procedure, we found an AB improvement when the target category was switched from the previous trial compared to when it was repeated from the previous trial. Findings appear inconsistent with the temporary loss of control account of the AB and support the hypothesis that AB results from an over-investment of attentional control.

1. Introduction

We know from the daily experience that our mind is considerably efficient in the conscious analysis of the visual world. However, daily errors also suggest that this efficiency is severely impaired when multiple pieces of information must be attended to in a very short time. Imagine two relevant events occurring rapidly in succession, as it happens in many daily situations (e.g., driving a car). How long does our attention dwell on the first event (e.g., the brake lights of the car ahead of you) before it can be efficiently reallocated to the second one (e.g., a turn indicator), while at the same time suppressing irrelevant surrounding information (e.g., a talking passenger)?

In the past 20 years, researchers tried to answer this question by varying the time interval between two visual events (targets) presented rapidly among many irrelevant events (distractors), in order to determine the time necessary for detection of the second event after seeing the first. It has been observed that after processing the first target event, the visual attention undergoes a "blind" latency period of approximately 300 ms during which any new relevant event occurring cannot be consciously detected. This phenomenon has been termed *attentional blink* (AB), and consists experimentally of the inability to successfully report the second of two target stimuli (T1 and T2) interspersed among distractors in a rapid serial visual presentation (RSVP) when T2 is presented within 200–500 ms of the appearance of T1 (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992; for reviews Dux and Marois (2009); Martens and Wyble (2010)). Interestingly, when the two targets are adjacent, which means that T2 is presented immediately after T1 without intervening distractors, there is little or no deficit in T2 identification (Visser, Bischof, & Di Lollo 1999; Visser, Zuvic, Bischof, & Di Lollo, 1999). Such an absence of the second-target deficit at lag 1 is often referred to as the *Lag-1 sparing effect*.

The AB has been taken as evidence of the limitations in the rate at which visual attention can create distinct mental representations that are accessible by awareness, attracting much interest as an effective means to study access mechanisms to consciousness (Asplund, Fougnie, Zughni, Martin, & Marois, 2014; Lasaponara, Dragone, Lecce, Di Russo, & Doricchi, 2015; Pincham & Szűcs, 2012; Sergent, Baillet, & Dehaene, 2005). Indeed, behavioral and electrophysiological evidence indicate that T2 undergoes some perceptual and semantic processing even when it is not consciously reported (Luck, Vogel, & Shapiro, 1996; Martens, Wolters, & van Raamsdonk, 2002; Pesciarelli et al., 2007; Sergent et al., 2005; Visser, Merikle, & Di Lollo, 2005; Vogel, Luck, & Shapiro, 1998).

Initially, the AB was interpreted as the consequence of a capacity-limited second stage of processing that is necessary for conscious processing and cannot be accessed by T2 as long as T1 occupies that stage (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Ward, Duncan, & Shapiro, 1996). On this ground, when T2 appears early after T1, it goes undetected because of the delay induced by conscious processing of T1. During the time of T1 consolidation, the pre-conscious trace of T2 decays below the threshold for recognition. In contrast, when T2 appears at longer time intervals after T1, it can be consciously detected because at the time T2 pre-conscious trace is consolidated the processing of T1 is terminated and T2 can gain access to conscious processing (Chun & Potter, 1995; Raymond et al., 1992; Sergent et al., 2005; Shapiro, Raymond, & Arnell, 1994).

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More recently, several pieces of evidence have seriously undermined this view. For example, many studies have demonstrated that the accurate report for sequences of three targets is possible without AB as long as no intervening distractors are presented (Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Nieuwenstein & Potter, 2006; Olivers, van der Stigchel, & Hulleman, 2007; Potter, Nieuwenstein, & Strohminger, 2008). Such a successive-targets advantage is difficult to explain in terms of resource depletion, as processing three targets consecutively should require attentional resources more than processing only two targets. Furthermore, a reduced AB has been reported when participants are provided with some distraction while doing the RSVP task, such as thinking about holiday or listening to music (Arend, Johnston, & Shapiro, 2006; Olivers & Nieuwenhuis, 2005), or when the focus on the identification task is reduced by a concurrent secondary task (Olivers & Nieuwenhuis, 2006; Taatgen, Juvina, Schipper, Borst, & Martens, 2009). Similar AB improvements have also been reported when a temporal cue indicating the time interval between the two target events is provided (Hilkenmeier & Scharlau, 2010; Martens & Johnson, 2005; Shen & Alain, 2011; Visser, Tang, Badcock, & Enns, 2014) or when the reports of T1 and T2 are combined in a single goal (i.e., reporting a combination of T1 and T2; Ferlazzo, Lucido, Di Nocera, Fagioli, & Sdoia, 2007; Ferlazzo, Fagioli, Sdoia, & Di Nocera, 2008).

All these findings have recently shifted explanations of AB from limited resource processing to top-down attentional control processes, emphasizing the role played by the attentional control in managing the competition between targets and distractors and in allowing the emergence to conscious perception of relevant events. Two types of control-based accounts of AB have recently been advanced. One of these accounts attributes the AB to a temporary loss of control (TLC) over the attentional filter during the second target identification (Di Lollo et al., 2005; Kawahara, Kumada, & Di Lollo, 2006). Specifically, the TLC account assumes that detecting targets and rejecting distractors require active control of the input filter. Once T1 is detected, the endogenous control over the input filter is temporarily compromised because the processing resources that are necessary to maintain the attentional set are also required for complete processing of T1. This leaves the attentional filter under the automatic (exogenous) control of subsequent input. Under these circumstances, if the item following T1 (T1 + 1) is a target, the input filter configuration remains unaltered, permitting the next target and the subsequent targets to be potentially processed, resulting in the lag-1 sparing and the successive-targets advantage. However, if T1 + 1 is a distractor, the lack of active control over the input filter leads to the automatic improper processing of the subsequent items, possibly producing the AB. On the other hand, based on the assumption that too much attention can be counterproductive, the other control-based account attributes the AB to an overzealous application of attentional control (Olivers & Meeter, 2008; Taatgen et al., 2009). Specifically, the overinvestment of control account (OC) assumes that all items of the RSVP initially receive some processing, leading to transient representations of these items. A second stage of processing is necessary for an item to be consolidated in working memory for later report, but this second stage of processing has limited capacity, so that only one (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998), or at most a few (Shapiro, Arnell, & Raymond, 1997), items can be accessed. An item enters this stage when its activation exceeds an internal activation threshold. If items other than T1 and T2 enter this limited-capacity stage, these items may interfere with target consolidation through competition. Allocating too many attentional resources to the RSVP stream leads to the entry of too many items in the second stage (e.g., by lowering the internal activation threshold or by boosting the activation of item representations), resulting in an increased interference between items, and an increased probability of distractor items to be consolidated in working memory, producing the AB.

These two accounts of AB lead to different predictions in situations of increased attentional control load during RSVP. If the AB is due to insufficient cognitive control for deep processing of T1 and concurrent active maintenance of the input filter configuration, as hypothesized by the TLC account, then any additional process that also requires attentional control should further reduce control resources devoted to monitoring perceptual input, resulting in further deterioration of the performance (i.e., increased AB). In contrast, if the AB is the consequence of too much attentional control that leads to improper processing of too many task-irrelevant items, as proposed by the OC account, then any additional control-demanding task would reduce the level of control committed to input monitoring so that a smaller number of potential interfering items are selected and compete for consolidation, reducing the probability of AB. In summary, the TLC predicts that decreasing the amount of attentional resources committed to input monitoring deteriorates performance, increasing the AB. Conversely, the OC predicts that decreasing the amount of attentional resources committed to input monitoring enhances performance, reducing the AB.

In the present study, we tested for predictions of these two mutually exclusive accounts of the AB by combining a typical RSVP task with a control-selective-demanding task, in order to tax control resources committed to input monitoring. Specifically, we induced participants to change or maintain the attentional settings for target selection on a trial-by-trial basis by switching or repeating the target class of stimuli to attend to oversuccessive RSVP streams. While selective attention operates by filtering stimuli based on specific features (e.g., shape or color), the attentional settings (i.e., whose specific feature must be used for selection) are established and modified by top-down attentional control processes according to the current goal. A large body of literature shows that the attentional switching is associated with performance cost (see Monsell (2003) for a review), and this switch cost[1] is due, at least partially, to the time necessary to implement a new attentional set (Dombrowe, Donk, & Olivers, 2011; Rogers & Monsell, 1995). For example, changing targets from trial-to-trial slows down the reaction times (RTs; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), and this impairment in performance is reduced when a visual cue about target identity is provided before target presentation (Vickery, King, & Jiang, 2005). Furthermore, increasing the switching preparation time by extending the cue-target interval reduces the cost (Meiran, Chorev, & Sapir, 2000). Interestingly, residual switch costs have been reported even when sufficient time is allowed for task preparation (e.g. Kimberg, Aguirre, & D'Esposito, 2000; Sohn, Ursu, Anderson, Stenger, & Carter, 2000), indicating that even long preparation does not eliminate the cost completely. Hence, when the target category is changed from the previous trial, the switching process requires the reconfiguration of the attentional filter by control processes. When this reconfiguration is required immediately before the RSVP stream, the control resources are not fully available for the RSVP processing up to when the reconfiguration process is completed. In contrast, when the target category remains the same on the successive RSVP stream, active control is not required as the attentional filter remains unaltered, and control resources are not strayed from the RSVP stream. Under these circumstances, the TLC predicts an increased AB deficit on switch compared to no-switch conditions because the category switching process would tax control resources that are also necessary for the control of the attentional filter, thus deteriorating performance. In contrast, the OC predicts a reduced AB deficit on switch compared to no-switch conditions because the category switching process would reduce the amount of attentional control committed to the RSVP task, limiting the number of potential interfering items that can be

[1] When the switching occurs within a mixed block of trials, namely when the task-relevant information is changed or repeated on a trial by trial level, the switching cost is related to the implementation of the new attentional set and traditionally it is called "switch cost" to differentiate from the "mixing cost" arising when the task-relevant information is changed or repeated on separated blocks of trials and that is related to the maintenance of two attentional sets in working memory.