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The Role of Spatial Switching in the Attentional Blink

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The attentional blink (AB) is a well-established paradigm in which identification of a target T2 is reduced shortly after presentation of an earlier target T1. An important question concerns the importance of backward masking during the AB. While task switching has been found to be a strong modulator mediating the AB without any masking of T2, the present study investigated whether spatial switching could similarly produce an AB without masking. Using a spatial AB paradigm in which items appeared at different locations; we found (a) a significant AB without backward masking of T2 but no AB when no distractors followed T2, (b) no evidence for Lag 1 sparing. These findings show that when there is a spatial switch between the targets, presenting the distractor following T2 at the same location than T2 (backward masking) is not a necessary condition for the AB to occur, but T2 has to be followed by surrounding distractors (appearing at different locations than T2). This pattern of data confirms that spatial switching is a robust modulator of the AB, but to a less extent than task switching.
Keywords: attentional blink, spatial switch, task switch, masking, temporal attention, spatial attention.

El parpadeo atencional (PA) es un paradigma muy utilizado cuyo principal resultado se traduce en una reducción temporal en la identificación de un *target* (T2) que se presenta seguido de otro *target* (T1). Una de las claves que provoca este efecto es el enmascaramiento hacia atrás que tiene lugar durante el PA. Sin embargo, estudios previos asumen que el *cambio de tarea* es uno de los moduladores más potentes en la aparición de PA sin enmascaramiento del T2; el objetivo de este trabajo se centró en probar si otro tratamiento, el *cambio espacial* podría dar lugar a un efecto de PA similar, esto es, sin enmascaramiento. Un paradigma de PA con presentación de los ítems en diferentes localizaciones condujo a los siguientes resultados: (a) efecto significativo de PA sin enmascaramiento hacia atrás de T2, pero no PA sin la presencia de distractores después de T2; (b) esto no se confirmó en la posición 1; los resultados sugieren que si hay un cambio espacial entre los targets, presentar un distractor seguido de T2 y en su mismo lugar (enmascaramiento hacia atrás) no necesariamente va a facilitar la aparición de PA, sino que es necesario que T2 vaya seguido de distractores pero presentados en diferentes localizaciones. Este patrón de datos confirma que el cambio espacial es un importante modulador en la aparición de PA, aunque en menor medida que el cambio de tarea.
Palabras clave: parpadeo atencional, cambio espacial, cambio de tarea, enmascaramiento, atención temporal, atención espacial.

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Dealing with the considerable amount of visual information from the environment requires individuals to select relevant information in the stream of spatio-temporal events. Yet, attentional selection can suffer from severe limits, as evidenced in the Attentional Blink (AB) phenomenon (Marois & Ivanoff, 2005). In a typical AB paradigm, subjects are presented with a stimulus stream using Rapid Serial Visual Presentation (RSVP) and are instructed to report the two targets embedded in a stream of distractors. The AB effect refers to the impairment for identification or detection of the second target (T2) when presented briefly (within 200-600 ms) after the first target (T1) (Raymond, Shapiro, & Arnell, 1992). The magnitude of the AB effect is known to vary as a function of the temporal lag between the two targets. In a typical AB effect, performance on T2 is U-shaped curved: it is relatively high at Lag 1 (when T2 is presented directly after T1), drops substantially at Lags 2 and 3, and then recovers at longer lags. The relatively unimpaired performance at Lag 1 is referred to as Lag 1 sparing. While the AB was initially attributed to the limited attentional resources (Raymond et al., 1992), research has converged on the idea that the AB can arise from a multiplicity of factors which can be necessary and/or sufficient (e.g., Nieuwenstein, Van der Burg, Theeuwes, Wyble, & Potter, 2009).

Among the factors that contribute to the AB, the switch between T1 and T2 was found to be of particular importance. Basically, the AB effect can be viewed as an attentional switch cost reflecting the difficulty to switch attention from T1 to T2 when it appears briefly after T1. Research on the factors modulating the AB revealed that additional types of switch can contribute to the AB effect (Visser, Bischof, & Di Lollo, 1999). Among these types of switch, task switching and spatial switching are of particular importance. Indeed, in an experiment in which participants had to perform two different tasks on T1 and T2 (T1 was a diagonal line segment whose orientation was to be reported and T2 was a letter to be identified), Kawahara, Zuvic, Enns, and Di Lollo (2003) reported that such a task switching between T1 and T2 was sufficient to produce the AB without backward masking of T2. This means that the task switch cost coupled with the attentional switch cost are sufficient to reduce significantly T2 visibility at short lags. On the other side, AB effect has also been modulated by spatial switching. Indeed, it has been repeatedly shown that when T1 and T2 appeared at different locations in an AB task, performance on T2 was monotonic rather than U-shaped (e.g., Duncan, Ward, & Shapiro, 1994; Visser, Zuvic, Bischof, & Di Lollo, 1999; Breitmeyer, Ehrenstein, Pritchard, Hiscock, & Crisan, 1999). In other words, in such conditions, performance on T2 varied linearly as a function of lag. Moreover, Kristjánsson and Nakayama (2002) showed that recovery from the AB is faster when the two targets are spatially distant compared to when they are nearby.

It is worth noting that in most of previous AB studies that included spatial switching, targets were backward masked (e.g., Visser, Zuvic et al., 1999; Kristjánsson & Nakayama, 2002). Numerous studies showed that the masking of the targets is a necessary condition for the AB to occur (e.g., Giesbrecht & Di Lollo, 1998; Brehaut, Enns, & Di Lollo, 1999). Thence, when investigating whether a particular factor is sufficient or not to produce the AB, it might not be suitable to mask the targets (Nieuwenstein et al., 2009; Kawahara et al., 2003). To our knowledge, there is only one study that investigated the influence of spatial switching on the AB without backward masking of the targets. In this study realized by Breitmeyer et al. (1999), RSVP items in the AB task were presented at one, four, or nine possible locations. Such a task has the advantage of using a RSVP stream with targets items being temporally surrounded by distractors that cannot act as backward masking stimuli. Breitmeyer et al. (1999) reported that while a standard U-shaped performance on T2 was found when items appeared at one location (i.e., in this condition, all stimuli appeared sequentially at the same location so that targets were backward masked), performance was monotonically related to lag with no Lag 1 sparing when spatial switching was involved. In this experiment, the impaired performance on T2 at short lags could be attributed solely to both temporal and spatial attention shifts as masking was not involved. However, even though targets were not backward masked, they were still followed by surrounding distractors. In particular, it could be that distractors following T2 also contributed to the reduction of T2 visibility at short lags.

In summary, findings from previous studies suggest that the sufficiency of spatial switch to produce AB is not conclusive yet. In order to address this issue, we conducted two experiments. The aim of Experiment 1 was to determine whether backward masking is necessary by replicating the findings of Breitmeyer et al. (1999). In Experiment 2, we tried to figure out whether the surrounding distractors are needed to produce AB. For that purpose, we used a task similar to that used by Breitmeyer et al. (1999) in which RSVP items appeared at different locations on a virtual circle rather than on a single location.

Experiment 1

The goal of Experiment 1 was to replicate the findings of Breitmeyer et al. (1999) who reported a monotonic AB when spatial switching was involved and the targets were unmasked. In the present experiment, each item in the RSVP stream could randomly appear at one of eight possible locations on the screen, with the constraint that two consecutive items could never appear at the same location. Thus, while there were always distractors following each target, T1 and T2 were unmasked.

Method

Participants

Fourteen undergraduate students (10 female and 4 male; mean age 22 years) participated in this experiment. All participants reported normal or corrected-to-normal vision. Two within-subject variables were manipulated: lag (1, 3, 5, 7, 9) and T1-T2 spatial Euclidian distance (3.7°, 6.9°, 9°, and 9.7° of visual angle).

Stimuli and Apparatus

Stimuli were presented in Arial font and subtended 1° of visual angle at a viewing distance of approximately 57 cm. All stimuli were white alphanumeric characters, centrally displayed on a black background on a 17" CRT monitor, and subtended approximately 1° of visual angle. The distractor items were digits 1 through 9. The targets items were capital letters (A, B, C, D, E, F, G, H, J, K, L, M, N, P, R, S, T, U, V, W, X, Y, and Z). The experiment was programmed in MATLAB, using the Cogent Toolbox and was conducted on PC computer with a 60 Hz vertical refresh rate.

Procedure

After a fixation cross presented for 500 ms, a 21 items RSVP stream was presented.

Each item was displayed for 83 ms and appeared at one of eight positions regularly arranged on an imaginary circle located at the center of screen. The fixation cross remained at the center of the screen throughout each trial. On any given trial, the distractors and the two targets were selected randomly from the digits and letters sets, respectively. The number of distractors preceding T1 varied between 5 and 8 so that T1 position in the RSVP stream was unpredictable. T2 was presented at lags 1, 3, 5, 7, and 9 (respectively 83, 250, 417, 583, and 750 ms after T1) and was followed by a constant number of distractors (6). Since 5 lags and 4 visual angles were manipulated, there were 20 cells in the design. Participants received 15 trials for each cell (60 trials for each lag), in random order. The experimental session included five blocks of 60 trials each (separated by a brief resting period), and was preceded by a practice session with 20 trials. Participants were instructed to maintain fixation on the central cross throughout each trial. They were able to do this without difficulty after some practice. At the end of each trial, observers were asked to type their responses with the keyboard without time pressure and to be as accurate as possible but to guess when necessary. The first and second targets were always to be identified (see Figure 1).

Results and Discussion

Table 1 shows the mean accuracy in T2 identification, pending that T1 was correctly identified, as a function of lag and T1-T2 spatial distance (mean T1 accuracy was 80.1%). The data from the experiment were submitted to a two-way analysis of variance design, with lag and T1-T2 spatial distance as within-subjects factors. Results showed a significant main effect of lag, $F(4, 48) = 5.45$, $p < .001$, indicating that T2|T1 accuracy increased with lag (73.5% in lag 1, 84.4% in lag 9; see Figure 2). Post-hoc comparisons revealed a significant blink effect at lag 1,

Table 1
Accuracy (in %) as a Function of Lag and T1-T2 Spatial Distance (T1-T2 dis.) in Experiments 1 and 2

Exp.	T1-T2 dis. (°)	Lag 1		Lag 3		Lag 5		Lag 7		Lag 9	
		M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
1	3.7	76.3	4.5	81.5	3.5	85.7	2.6	76.0	3.7	86.8	2.1
	6.9	68.5	3.7	75.1	3.9	79.7	2.8	87.9	3.1	79.3	4.5
	9	87.9	3.9	82.4	2.5	83.1	2.9	85.1	4.0	85.2	3.1
	9.7	61.2	7.2	75.9	4.1	76.8	6.2	82.7	4.3	86.3	4.1
2	3.7	59.2	9.6	57.3	6.6	61.5	4.6	56.4	6.3	55.2	8.5
	6.9	60.9	5.7	68.9	6.4	59.6	5.3	66.1	7.5	66.2	5.8
	9	53.0	8.1	62.4	8.8	64.0	5.0	49.9	4.6	59.4	5.8
	9.7	62.1	7.4	70.2	8.9	63.0	8.4	66.7	9.4	71.6	7.5

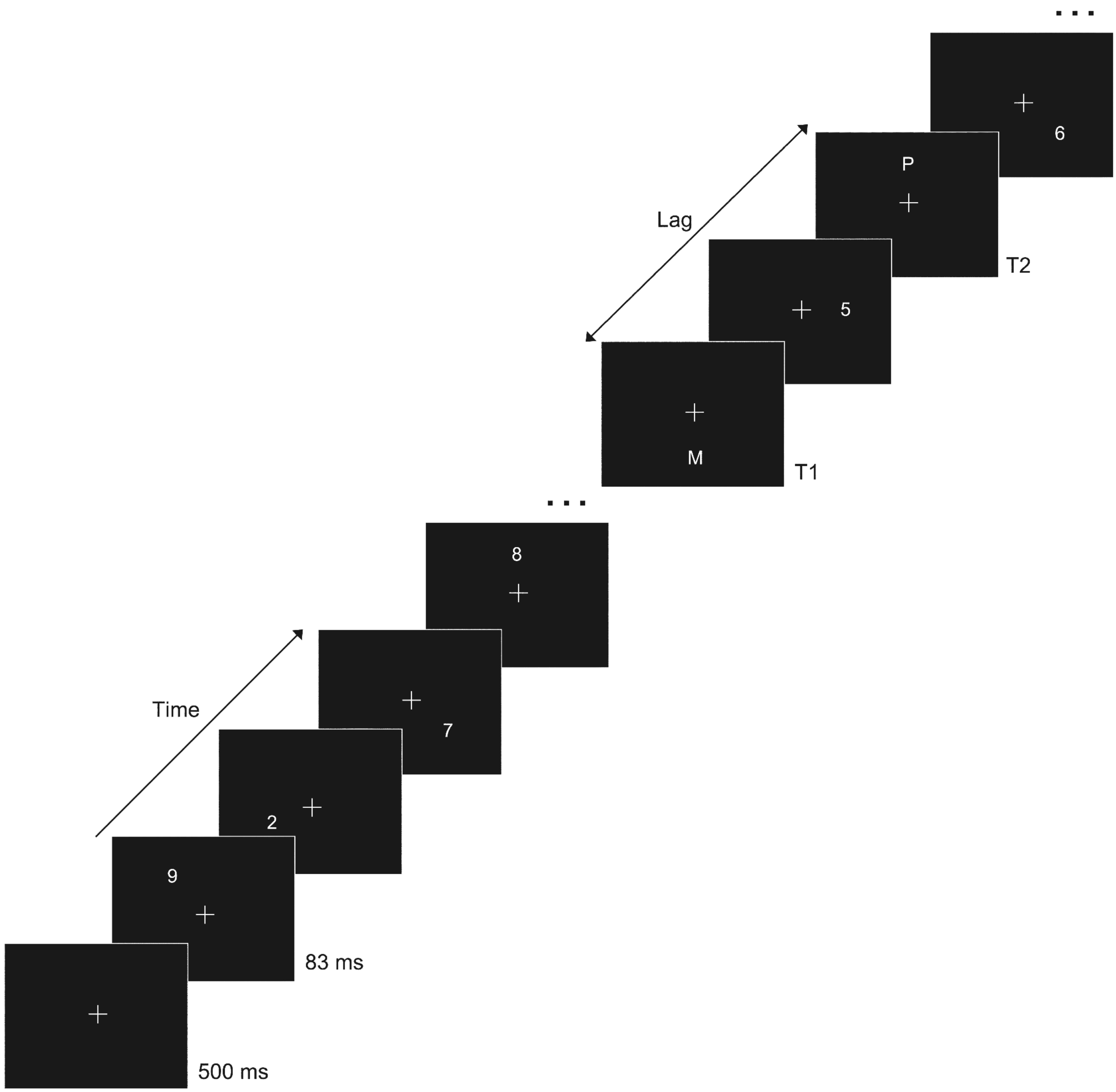

Figure 1. Example RSVP stream of the spatial attentional blink task.

$t(51) = 3.28$, $p < .001$, and at lag 3, $t(51) = 3.14$, $p < .005$. Note that in these post-hoc comparisons aimed at determining any blink effect, comparisons were between any lag and the lag 9[1]. There was also a significant main effect of T1-T2 spatial distance, $F(3, 36) = 5.79$, $p < .005$. T2|T1 accuracy was here also higher when T1 and T2 were spatially close (81.3% for the 3.7° modality) than when the two stimuli were spatially distant (76.6% for the 9.7° modality). The analysis revealed also that lag and T1-T2 spatial distance interacted significantly, $F(12, 144) = 2.60$, $p < .005$. This interaction was caused by the fact that T2|T1 accuracy improved significantly faster when T1 and T2

[1] In a typical AB study, two situations can be considered as a baseline, in which T2 does not suffer a lack of attention induced by T1. The first case refers to conditions in which T1 is replaced by a distractor whereas the second case refers to conditions in which T2 is presented at long lags. Indeed, performance on T2 typically recovers from the AB from 500 ms and ceils from 600 ms, so that in the latter case, T2 should be presented at least 600 ms after T1 (e.g., Chun & Potter, 1995). In our experiments, the lag 9 condition was a proper baseline since T2 was presented 747 ms after T1.

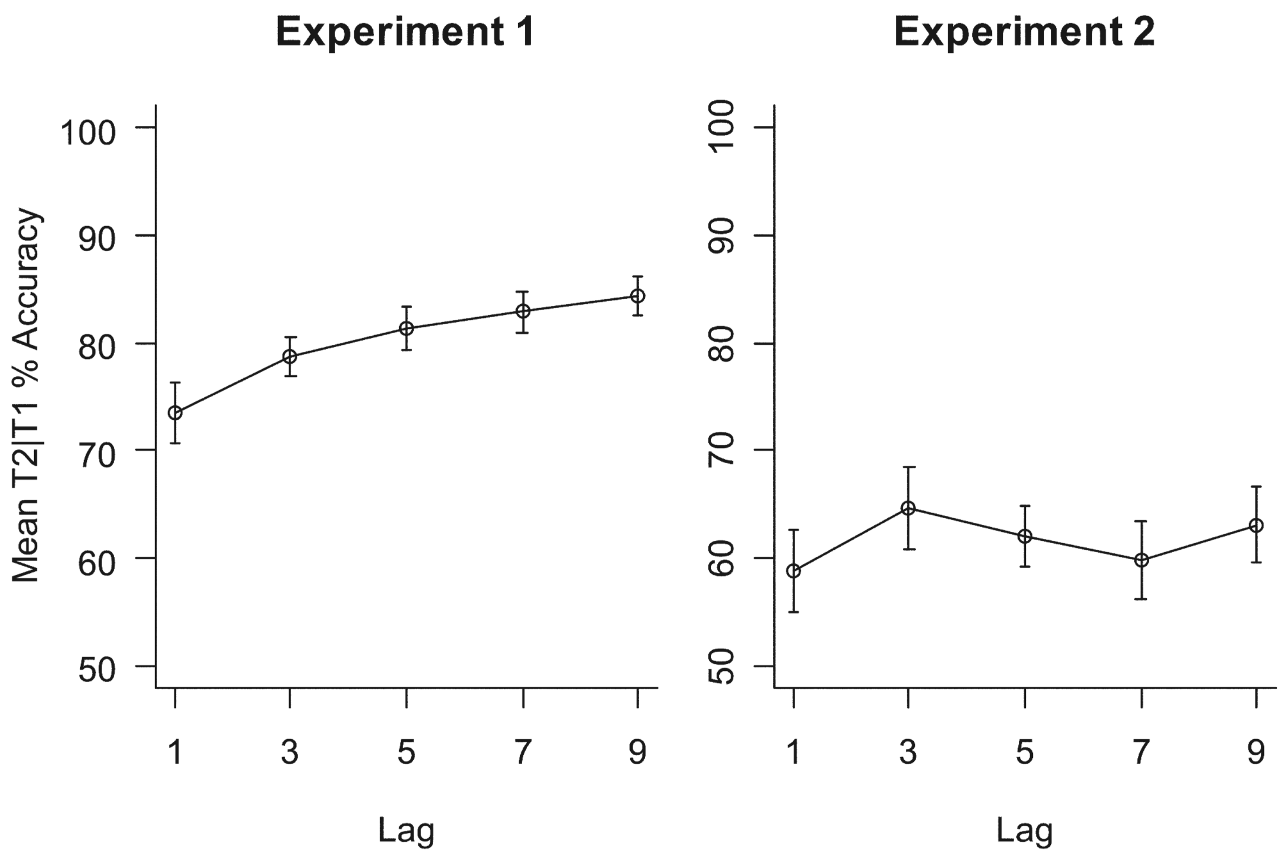

Figure 2. Mean T2|T1 accuracy as a function of lag in Experiments 1 and 2.

were spatially distant. Indeed, Table 1 shows that while the difference between accuracy at lag 3 and accuracy at lag 1 was 5.2% (81.5% - 76.3%) in the 3.7 spatial condition, this difference was 14.7% (75.9% - 61.2%) in the 9.7 spatial condition. This pattern was also reflected by the fact that at lag 1, T2|T1 accuracy was marginally lower when the two targets were spatially distant (9.7 condition) than when they were spatially close (3.7 condition), $t(12) = 1.92$, $p = .07$, while there was no longer such difference at lag 9.

These findings replicated those reported by Breitmeyer et al. (1999). Indeed, we also found a monotonic curve rather than the classical U-shaped curve of the AB. Indeed, no Lag 1 sparing (i.e., preserved T2 accuracy at lag 1) was observed in this experiment. Furthermore, it should be noted that we obtained similar results as Breitmeyer et al. (1999) despite a procedural difference between the two experiments. This difference was related to how stimuli were displayed. While in our experiments each stimulus appeared randomly at one of eight positions regularly arranged on an notional circle, each stimulus appeared at randomly at one of nine positions defined by a notional 3 × 3 matrix in the experiments of Breitmeyer et al. (1999) (in both sets of experiments, two consecutive stimuli could never appear at the same location). Overall, the results of Experiment 1 strengthen the generality of the hypothesis that no Lag 1 sparing is observed when spatial switching is added to the AB (Visser, Bischof et al., 1999).

Experiment 2

This second experiment was designed to test whether spatial switching is sufficient to produce the AB without any distractor following T2. We reasoned that if temporal and spatial switches of attention on T2 are sufficiently strong at the shortest lags, then the AB effect should still be observed even when no distractor follows T2.

Method

Participants

Eighteen undergraduates (12 female and 6 male; mean age 22 years) participated in this experiment. All participants reported normal or corrected-to-normal vision. None of them was involved in any of the other experiments reported here.

Stimuli and Apparatus

Stimuli, design, and apparatus, were identical to those of Experiment 1.

Procedure

Procedure was identical to the one used in Experiment 1, with the following two exceptions. First, there was no distractor following T2. Compared to Experiment 1, distractors following T2 were replaced by blank screens. Secondly, T2 intensity was reduced in order to avoid ceiling effects. Indeed, a pilot study revealed that the mere absence of distractors following T2 while keeping the same stimuli intensity as in the previous experiments leads to almost perfect performance. Thus, T2 intensity was reduced to 85% of its initial value.

Results and Discussion

The mean T1 accuracy was 92%. Table 1 shows the mean T2 accuracy as a function of lag and T1-T2 spatial distance. Results showed no significant effect of T1-T2 spatial distance or lag (all Fs < 1). This absence of AB effect in this experiment suggests that contrary to task switching, spatial switching cannot mediate the AB without any masking of T2.

General Discussion

The AB effect can be viewed as an attentional switch cost reflecting the difficulty to switch attention from a first target to a second temporally close target. Numerous studies have investigated the modulating factors of the AB. It has been shown that among the possible types of switch between T1 and T2 other than the basic attentional switch, spatial switching and task switching are important modulators of the AB. The present study investigated the role of spatial switching in the AB. First, in line with previous findings obtained in the study of Breitmeyer et al. (1999) which also involved a spatial switch between T1 and T2 without backward masking, we found a monotonic rather than a U-shaped AB with no evidence for Lag 1 sparing. This finding supports the idea that the effect obtained when adding spatial switching to the AB task is qualitatively different from the typical AB effect (Visser, Bischof et al., 1999). Moreover, we replicated the finding of Kristjánsson and Nakayama (2002) showing that recovery from the AB over time is faster when the two targets are spatially distant.

Secondly, we showed that contrary to task switching, spatial switching cannot produce the AB without any masking of T2. Indeed, this type of switch requires the presence of distractors surrounding T2 for the AB to occur whereas task switching does not (Kawahara et al., 2003). This finding suggests that spatial switching is a weaker modulator of the AB than task switching. In other words, the couple (attentional switch + task switch) could mediate the AB without any masking of T2 while the couple (attentional switch + spatial switch) cannot. This can be explained by the switch account of the AB (Visser, Bischof et al., 1999). Actually, this account assumes that processing of the second target is delayed while the system is being reconfigured following a switch. At short lags, the representation of the second target undergoes continuous decay resulting from the combined delays induced by the switch and first-target processing. Within this conceptual framework, one can assume that the duration of the decay depends on the extent to which the system has to be reconfigured to process the second target. Therefore, the fact that spatial switching seems to be a weaker modulator of the AB than task switching could be related to the fact that the former tends to produce smaller switch costs than the latter (Visser, Bischof et al., 1999). Indeed, when the switch between T1 and T2 is sufficiently important, the decay in T2 processing is such that when the system is configured, the representation of T2 is no longer available. In this case, no masking of T2 is needed since T2 cannot be recovered. This scenario happens when there is a task switch between T1 and T2 (Kawahara et al., 2003). On the other hand, when the switch between T1 and T2 is less important, the decay in T2 processing is such that no backward masking is required. However, this decay is not long enough to prevent T2 from recovery. This might happen when the only switch between the targets is a spatial switch. In this case, we showed that while an AB can occur without backward masking of T2, a light masking of T2 is still necessary (i.e., the presence of distractors surrounding T2).

Finally, our results are in line with the idea that the AB effect can arise from a multiplicity of factors with each factor contributing more or less to the phenomenon. While early models of the AB were focused on the role of resource depletion (Raymond et al., 1992), subsequent research highlighted the role of others factors such like switching (Visser, Bischof et al., 1999) and distractor interference (Di Lollo, Kawahara, Ghorashi, & Enns, 2005). This has led to the idea that the AB is not a unitary phenomenon (Kawahara, Enns, & Di Lollo, 2006). Such a view would eventually reveal the factors that are necessary and/or sufficient to produce the AB (Nieuwenstein et al., 2009).

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