

# The attentional blink and lag 1 sparing are nonspatial

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The attentional blink (AB) refers to the finding that the perception of the second of two targets (T2) is impaired when presented in close temporal proximity to the first target (T1). An exception to this deficit occurs when T2 immediately follows T1, an effect referred to as *lag 1 sparing*. So far, it has been unclear whether the AB is location specific or nonspatial in nature. Most demonstrations of an AB across different locations have shown an absence of lag 1 sparing, due to accompanying spatial switch costs. This means that the AB pattern itself may be explained through such switch costs. In this study, to minimize spatial switch costs, attention was made to move continuously across multiple locations by aid of a cue. An AB across different locations was found, including lag 1 sparing. We conclude that the AB and lag 1 sparing are not tied to a location but represent a central deficit, in line with current theory.

When two targets are presented within a stream of distractors in rapid serial visual presentation (RSVP), perception of the second target (T2) is considerably reduced when it appears in close temporal proximity to the first (T1). This deficit, called the *attentional blink* (AB; Raymond, Shapiro, & Arnell, 1992), has been taken to reflect a reduction in visual attention, leading to limited awareness or memory consolidation for T2. A number of theories assume that the processing of T1 requires limited-capacity attentional resources at the level of (visual) working memory, thus leaving fewer of these resources for T2 (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Shapiro, Raymond, & Arnell, 1994). Others have proposed that attention is suppressed or disrupted by the distractors directly following T1, since these items do not correspond to the observer's attentional set (Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Olivers, 2007; Olivers & Meeter, 2008; Olivers, van der Stigchel, & Hulleman, 2007; Raymond et al., 1992). Targets presented after these distractors may then fail to enter (visual) working memory. Whatever the exact mechanism, the theories have in common that the locus of the deficit is relatively central, occurring either in or just before a working memory stage. Such a central locus would lead to the prediction that the AB is a largely nonspatial phenomenon. In other words, the deficit should not be limited to the location of T1.

So far, there have been relatively few studies systematically investigating the spatial extent of the AB (Barriopedro & Botella, 1998; Dell'Acqua, Sessa, Jolicoeur, & Ro-

bitaille, 2006; Jefferies, Ghorashi, Kawahara, & Di Lollo, 2007; Juola, Botella, & Palacios, 2004; Kristjánsson & Nakayama, 2002; Olivers, 2004; Peterson & Juola, 2000; Shih, 2000; Visser, Zuvic, Bischof, & Di Lollo, 1999). Kristjánsson and Nakayama used eight simultaneous RSVP streams at different locations and reported a reduction of the AB the farther away T2 was from T1. This suggests that the AB is, at least in part, spatially localized. This would be consistent with the recent boost-and-bounce theory of Olivers and Meeter (2008), which suggests that the inhibition caused by the post-T1 distractor is partially location based (although this is not crucial to the central tenet of the theory; see the General Discussion section). Other studies investigating the spatial nature of the AB have typically used two streams presented to either side of fixation and have shown a clear deficit when T2 was presented in a different stream than T1. Thus, it appears that an AB occurs across locations, consistent with a central deficit.

However, there is a potential problem with the interpretation of many of these multiple-stream studies. The crucial condition involves T1's being presented in one stream and T2 in another. Thus, the observer needs to *switch* attention from one location to the other. By this we mean that attention needs to disengage or unfocus from one location and then reengage or refocus on a different location. Alternatively, attention may need to expand its focus from one stream to two streams. For this to happen, selection biases will need to be reconfigured. Regardless of whether such

reconfiguration occurs in a graded or more discontinuous fashion, it comes at a cost: Processing at the new location is suboptimal as long as spatial attention is still focused on the old location. It is therefore possible that this spatial switch is the cause of the deficit for T2 in the other stream, rather than a central, nonspatial AB. It goes without saying that such spatial shifts of attention need not be the same mechanism as the one involved in the AB proper. In fact, there have been strong indications that the need to switch from one stream to the other indeed results in costs. The classic work by Sperling and colleagues (Reeves & Sperling, 1986; Sperling & Weichselgartner, 1995; Weichselgartner & Sperling, 1987), using a paradigm very similar to that of the AB, has shown that well-trained observers receiving a cue to switch streams need around 200–250 msec to reach their optimal level of processing again. Also, within the AB paradigm itself, there has been strong evidence for spatial switch costs across multiple streams. This evidence is based on a phenomenon that more often than not accompanies the AB and has become one of its hallmarks: *lag 1 sparing*. Lag 1 sparing refers to the finding that T2 report is typically unaffected when T2 immediately follows T1, at lag 1 (although it is not necessarily limited to lag 1; Bowman & Wyble, 2007; Di Lollo et al., 2005; Olivers et al., 2007). Lag 1 sparing has been explained by assuming a certain tardiness in the closing of an *attentional gate*, so that T2 can piggyback on T1 processing. Of central interest to the present study, lag 1 sparing is absent when the AB task involves either a task switch or a spatial switch (see Visser, Bischof, & Di Lollo, 1999, for a review). At the same time, the temporary deficit for T2, taken as indicative of an AB, still occurs. The conclusion has been that T1 causes a nonspatial AB for T2 (as demonstrated by the temporary deficit) but that lag 1 sparing may reflect an independent mechanism that is being camouflaged or abolished by the need to switch (Juola et al., 2004; Peterson & Juola, 2000; Visser, Bischof, & Di Lollo, 1999). However, this reasoning remains vulnerable to the possibility that not only the absence of lag 1 sparing, but also the *entire* cost for T2 is caused by spatial switching, while the AB itself is then still locked to the location of T1. Both a nonspatial AB and a spatial switch cost predict a performance deficit for the new location. Conversely, what may look like the same deficit (in terms of data) need not reflect the same mechanism. Finally, whether lag 1 sparing and the AB are completely independent processes remains open to debate (a debate that is not crucial to the present argument). Recent work suggests that sparing and blinking are intricately related (Di Lollo et al., 2005; Nieuwenstein & Potter, 2006; Olivers, 2007; Olivers & Meeter, 2008; Olivers et al., 2007).

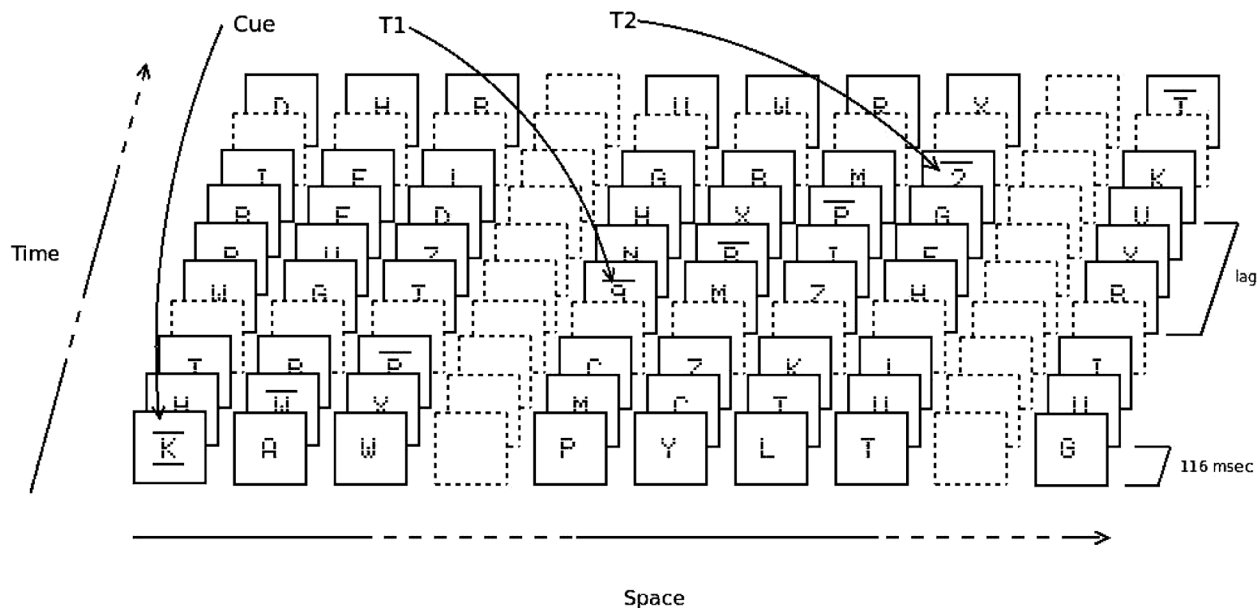
The proper criterion for a nonspatial AB would thus be the occurrence of a temporary T2 deficit when presented in a different stream than T1, but with lag 1 sparing still intact. If lag 1 sparing occurs, the subsequent deficit cannot be due to spatial switch costs, since a switch cost would not spare lag 1. A recent study by Jefferies et al. (2007; see also Shih, 2000) meets this criterion. In a double-stream experiment with two groups of participants, one group was told in which stream T1 was going

to be presented, and the other was not. T2 could then appear in the same stream as T1 or in the other stream. When targets were presented in different streams, only the group without foreknowledge of T1 location showed an AB pattern including lag 1 sparing. Apparently, when participants do not know where T1 will appear, attention is distributed across the two streams, and thus there is little to no need to switch location or focus. In contrast, when attention is already focused on one stream, it will need to be shifted or expanded to the other stream in order to detect T2, resulting in the absence of lag 1 sparing. However, the evidence still remains somewhat inconclusive. The measured lag 1 sparing effect across the two streams in the Jefferies et al. study was substantial but not complete: Lag 1 performance fell about halfway between the worst performance (i.e., the trough of the blink at lag 3) and the best performance (i.e., for T1 or for T2 at the later lags, when the observers had recovered from the AB). It is therefore possible that the observers, rather than evenly distributing their attention across the streams, arbitrarily gave priority to one stream over the other, resulting in lag 1 sparing when this happened to be the T2 stream. This account would also explain the difference in mean T1 report accuracy between the group that knew the T1 location (76.5%) and the group that did not (67.2%). Furthermore, it may be the case that the AB is still tied to a single location but that, when the target positions are uncertain, attention will treat the two locations of the streams as a single location, with the AB then applying to the set of streams. Indeed, this is what Jefferies et al. appear to have advocated when they proposed that the attentional focus is expanded so that it encompasses both streams (see also Jefferies & Di Lollo, 2009). Finally, theoretically, the uncertainty about T1 per se may, for one reason or another, have caused the lag 1 sparing, rather than the presumed effects that such uncertainty has on spatial attention settings. Other work has shown that RSVP processing is sensitive to strategic processing, as induced by cuing, temporal expectancies, and target frequency (Akyürek, Toffanin, & Hommel, 2008; MacKay & Juola, 2007; Martens, Elmallah, London, & Johnson, 2006; Martens & Johnson, 2005), and such effects may extend to uncertainty caused by spatial manipulations. We therefore sought to test the spatial specificity of the AB again.

## EXPERIMENT 1

The aim of the present study was to reinvestigate the spatial properties of the AB. To this end, we presented 27 different RSVP streams of 27 items each in a horizontal row across the screen (see Figure 1). In the *different-stream* conditions, T1 and T2 were embedded in one of these spatially separated streams. Performance was compared with a *same-stream* control condition, in which both targets were embedded in one and the same stream, and with *single-target* control conditions, in which only T2 was presented.

The crucial manipulation was the presence of a cue. In the different-stream condition, this cue traveled from left



**Figure 1.** Illustration of the experimental setup used throughout the experiments. Twenty-seven temporally synchronous rapid serial visual presentation streams were placed in a horizontal line in the middle of the screen. Each presented a sequence of 27 items. In the different-stream condition in Experiment 1 (as illustrated here), the cue moved from left to right across the streams, at a speed of one position per lag. The first target (T1) was always presented at Position 10. Here, the second target (T2) is presented at lag 3 (which corresponds to Position 13).

to right across the 27 streams, at a speed of one position per lag. The cue was always valid in that, when T1 and T2 were presented, they would always occur in the cued location. T1 would always occur just before the center of the display, at spatial (and temporal) Position 10, with T2 following at different lags (and thus, positions), at a cued location. Without the cue, the task was virtually impossible to perform. We reasoned that attention would track the cue in its continuous motion across the different locations (Pylyshyn & Storm, 1988) and, because of this already continuous motion, it would have relatively little trouble disengaging from one item and shifting to the next item. In other words, attention would already possess a certain momentum in the direction of T2, and spatial switch costs would be minimized (cf. Pratt, Spalek, & Bradshaw, 1999; although see Snyder, Schmidt, & Kingstone, 2001). If so, lag 1 sparing would be expected to occur, comparable to that in a same-stream control condition in which the cue was static (since it indicated only a single stream). Importantly, a subsequent temporary deficit for T2 in the different-stream condition would then be strong evidence for a legitimate nonspatial AB. Furthermore, with 27 streams in total, it would be difficult to argue that such a deficit results from observers' treating the entire array as a single location. To equate for potential eye movement and eccentricity effects, we also included single-target control conditions with both moving and static cues.

## Method

**Participants.** Twelve students at the Vrije Universiteit Amsterdam (5 males; 1 left-handed; 18–32 years of age; average, 23 years) participated in return for monetary payment.

**Stimulus, Procedure, and Design.** Stimulus generation and response recording were done using E-Prime (Psychology Software Tools Inc., Pittsburgh). After a blank period of 1,000 msec, a black fixation cross of approximately  $0.8^\circ \times 0.8^\circ$  was presented in the middle left side of the display for 1,000 msec. This was followed by 27 sequentially independent RSVPs of 27 letters each, forming a horizontal array across the center of the display. The center-to-center distance between streams was  $0.9^\circ$ , and each measured approximately  $0.6^\circ \times 0.9^\circ$ . The letters were presented in Elektra font (available on a free license from [www.dafont.com](http://www.dafont.com)) and were dark gray ( $10 \text{ cd/m}^2$ ) on a light gray ( $38 \text{ cd/m}^2$ ) background. They were drawn randomly from the alphabet, excluding I, O, Q, and S (since they resemble digits too much), with the restriction that no two consecutive letters could be the same. The stimulus onset asynchrony (SOA) was 116 msec. On each trial, one or two letters in a stream were replaced with digits randomly drawn from 2 to 9, with the restriction that, in the case of two targets, they had to be different. In all the conditions, there was a cue consisting of two parallel horizontal lines ( $0.8^\circ$  visual angle, in black) presented above and below the streams at a distance of approximately  $0.2^\circ$ .

The participants were positioned directly in front of the left side of the screen (where the fixation cross would appear), at a distance of approximately 75 cm, and were told to move only their eyes, not their heads. This was done so that the observers could smoothly attend from left to right without having to cross the meridian (which may incur costs). After each trial, they were asked to identify all the targets and report these in an unspeeded manner by typing in the digits on a standard keyboard. The participants were encouraged to guess if uncertain and were told that target report order was irrelevant. Correctly identified targets that were entered in the wrong order were counted as correct. Feedback on accuracy was given after both targets had been reported.

There were three main factors: spatial dynamics (targets in different streams vs. targets in the same stream), lag (difference in temporal position between the two targets: 1, 2, 3, and 7), and number of targets (two targets vs. single target control). In the different-stream condition, the always valid cue was moved from left to right across

**Table 1**  
**Accuracy Scores in Experiment 1 As a Function of Number of Targets,**  
**Spatial Dynamics of the Display, and Lag Position Relative to the First Target**

No. Targets	Spatial Dynamics									
	Same Stream (Static)					Different Stream (Moving)				
	Lag 0	Lag 1	Lag 2	Lag 3	Lag 7	Lag 0	Lag 1	Lag 2	Lag 3	Lag 7
Single target	.95	.95	.95	.96	.95	.77	.81	.80	.77	.71
Dual target, T1		.89	.96	.92	.93		.72	.78	.80	.81
Dual target, T2		.93	.88	.85	.84		.71	.67	.56	.58
<i>Net AB</i>		-.02	-.07	-.11	-.11		-.10	-.13	-.21	-.13

Note—In the different-stream condition, different lags also corresponded to different positions. T1, first target; T2, second target; AB, attentional blink.

the 27 streams (changing one position per SOA), and thus, T1 and T2 appeared in different streams. T1 always appeared in Position 10, with T2 following at Spatial Position 11, 12, 13, or 17 (corresponding to the different lags). In the single-target control version of this condition, the cue moved in the same way, but there was only one target, which could appear in Position 10, 11, 12, 13, or 17. In the same-stream condition, the cue was static, fixed at the stream running on Position 10. Both T1 and T2 appeared in this stream, at the same lags as in the different-stream condition. In the single-target control, there was only one target, presented at the different temporal positions corresponding to the same lags. The spatial dynamics (same stream, different stream) and number of targets (single, dual) were blocked, whereas the different lags were mixed within blocks of trials.

The experiment began with 5 practice trials per single-target condition and 30 trials per dual-target condition. This was followed by the four blocks, each containing 20 trials for each target's possible temporal position. This resulted in 100 trials per block in the single target control conditions (since the single target could appear in Position 10, 11, 12, 13, or 17) and 80 trials per block in the dual-target conditions (since T1 always appeared in Position 10, but T2 in any of the four remaining positions). Block order was set according to a digram-balanced Latin square design. The experiment lasted approximately 50 min.

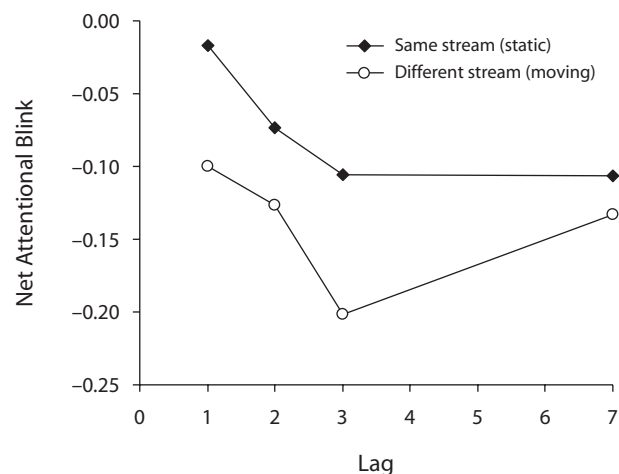
## Results and Discussion

**Single-target accuracy.** Single-target accuracy is shown in Table 1. A two-way within-subjects ANOVA, with spatial dynamics (same stream, different stream) and lag (0, 1, 2, 3, 7) as factors, revealed a significant main effect of spatial dynamics [ $F(1,11) = 23.17$ ,  $MS_e = .042$ ,  $p = .001$ ] and no other effects ( $F_s < 2$ ,  $p_s > .11$ ). Overall, as might be expected, target detection was worse in the different-stream condition (involving a moving cue) than in the same-stream condition (involving a static cue).

**Dual targets, T1 accuracy.** T1 accuracy for the dual-target condition is also shown in Table 1. A two-way within-subjects ANOVA, with spatial dynamics (same stream, different stream) and lag (1, 2, 3, 7) as factors, revealed a significant main effect of each but no interaction [spatial dynamics,  $F(1,11) = 24.93$ ,  $MS_e = .021$ ,  $p < .001$ ; lag,  $F(3,33) = 5.81$ ,  $MS_e = .004$ ,  $p < .01$ ; interaction,  $F < 1$ ,  $p > .4$ ]. As in the single-target condition, accuracy was, overall, worse in the different-stream (moving) condition than in the same-stream (static) condition. In both conditions, T1 performance was worst for lag 1 and then improved with lag. The deterioration for T1 at lag 1 is a common finding when lag 1 performance for T2 is quite good and probably reflects some direct competi-

tion between T1 and T2 when presented closely in time (Potter, Staub, & O'Connor, 2002).

**Dual targets, T2 accuracy.** In this and the subsequent experiments, T2 accuracy was analyzed only for those trials on which T1 was correct. The resulting scores are presented in Table 1. Then T2 performance was corrected for stimulus-related effects (i.e., eccentricity, the presence of motion, eye movements) by subtracting the equivalent single-target control condition. Note that this procedure may negate any overall effects of the number of targets (such as the additional memory or executive load for two targets), but such effects were not of central interest here. Furthermore, the lack of a difference between single-target performance and T1 performance in the dual-target condition suggests that such effects were small or absent. The resulting net AB effect is shown in Figure 2 (as well as in Table 1). A two-way within-subjects ANOVA, with spatial dynamics (same stream, different stream) and lag (1, 2, 3, 7) as factors, revealed significant main effects of each but no interaction [spatial dynamics,  $F(1,11) = 26.230$ ,  $MS_e = .055$ ,  $p < .001$ ; lag,  $F(3,33) = 3.959$ ,  $MS_e = .018$ ,  $p = .016$ ; interaction,  $F(3,33) = 1.201$ ,  $MS_e = .008$ ,  $p = .325$ ]. Overall, the task was more difficult in the different-



**Figure 2.** The net attentional blink effect in Experiment 1. Net values are calculated by subtracting accuracy scores in the single-target control condition from those in the corresponding dual-target condition.

stream (moving) condition than in the same-stream (static) condition. This is not surprising. Furthermore, performance was, overall, best for lag 1 and worst for lag 3, consistent with an AB. Note that there was no clear recovery from the AB at lag 7 in the same-stream condition. Usually, a recovery is found from about 400 msec onward. We have no clear explanation for the lack of recovery here, other than that the lags were insufficiently long to allow for recovery or observers occasionally give up looking at the stream altogether when T2 has not arrived within a certain time. We point out that a lack of recovery is not unique (e.g., Jefferies et al., 2007; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005; Shih, 2000).

The important finding was that a complete AB pattern, including lag 1 sparing, emerged in both the static same-stream and the moving different-stream conditions. This was further supported by an ANOVA focusing only on lags 1 and 3, which represent the greatest sparing and deepest deficit, respectively. Again, results showed significant main effects of dynamics [ $F(1,11) = 17.583$ ,  $MS_e = .043$ ,  $p = .002$ ] and lag [ $F(1,11) = 10.774$ ,  $MS_e = .014$ ,  $p = .007$ ] but no interaction between the two [ $F(1,11) = 2.179$ ,  $MS_e = .007$ ,  $p = .168$ ]. Thus, the costs for having T1 and T2 in different locations and the costs associated with the different lags were additive. It appears, then, that the AB deficit is not spatially bound to the T1 location but, indeed, is a more central impairment, consistent with current theories.

In the different-stream condition, the cue always moved from left to right across the streams, which meant that, depending on how well observers followed the cue, T1 and T2 may have appeared within the same hemifield. In various previous studies using multiple RSVP streams, the two targets appeared in different hemifields. Any previous switch costs (expressed as the absence of lag 1 sparing) may thus have reflected a switch between hemifields, rather than a pure spatial cost. We point out, however, that the same costs have also been found when T1 and T2 were presented in the same hemifield (Kristjánsson & Nakayama, 2002), when T1 was presented centrally and T2 at eccentricity (Visser, Zuvic, et al., 1999; this situation is most reminiscent of the present one), or when T1 and T2 were positioned on the vertical meridian (Potter et al., 2005; Potter et al., 2002).

## EXPERIMENT 2 No Lag 1 Sparing When Attention Switches Location

In the introduction we hypothesized that the lack of lag 1 sparing in many previous studies involving multiple RSVP streams was due to the necessity to switch attention from one location to the other. Experiment 1 was designed to use multiple streams but to reduce the necessity to switch—with the return of lag 1 sparing as the result. However, to conclude that it is really spatial switching that causes the absence of lag 1 sparing, we need to demonstrate that, in our displays, lag 1 sparing indeed disappears when a spatial switch is reintroduced. In Experiment 2A,

therefore, the cue was static, positioned on the stream that contained T1. In the *same-stream standard* condition, T2 was presented in the same-stream as T1, and thus we expected an AB including lag 1 sparing. The same was the case for the same stream control condition, in which both T1 and T2 appeared in the adjacent stream to the right of the cued stream (to control for any potential adverse effects of the cue itself). The crucial condition was the *different-stream switch* condition, in which T1 appeared in the cued stream and T2 appeared in the stream next to it on the right. Here, we assumed that attention would have to switch between streams and, thus, lag 1 sparing should be absent. Single-target control conditions were again included for each position.

Note that in the conditions just described, the cue always remained on the T1 stream, regardless of whether T2 then appeared in the same or in a different stream. In contrast, in the different-stream condition in Experiment 1, both T1 and T2 were always in the cued stream, since the cue moved from one stream to the next. To see whether cuing the different stream is in itself sufficient to cause lag 1 sparing to reemerge, we conducted Experiment 2B. In the different-stream cued switch condition, the cue first indicated the T1 stream, and then, immediately after T1 presentation, jumped to the adjacent stream to indicate T2's position. This way, any spatial switching might be aided by the cue and, when sufficiently sped up, cause lag 1 sparing to return.

## Method

**Participants.** Fifteen students at the Vrije Universiteit Amsterdam (7 males; 1 left-handed; 18–32 years of age, average 23 years) participated in Experiment 2A. Twelve students (4 females; all right-handed; 19–24 years of age, average 20 years) participated in Experiment 2B. All were paid €7 per hour.

**Stimulus, Procedure, and Design.** Apart from the following changes, Experiment 2A was the same as Experiment 1. The cue was always placed over Spatial Position 10. In the same-stream standard condition, both T1 and T2 appeared inside the cued stream. In the same-stream control condition, both appeared in the stream right next to the cue (on the right). In the different-stream switch condition, T1 appeared in the cued stream, and T2 appeared in the one next to it. Block order was set according to a Latin square design. The experiment lasted approximately 45 min. Experiment 2B was the same as Experiment 2A, except for the following. The different-stream switch condition was replaced with the different-stream cued switch condition. In this condition, T1 again appeared in the 10th stream, and T2 in the 11th stream, but immediately after T1, the cue jumped to the T2 stream. There was only one same-stream condition (always cued), and in this experiment, there was no single-target control condition.

## Results and Discussion

All of the following analyses are based on a two-way within-subjects ANOVA with spatial dynamics (in Experiment 2A, same-stream standard, same-stream control, different-stream switch; in Experiment 2B, same-stream standard, different-stream cued switch) and lag (1, 2, 3, 7) as factors.

**Single-target trials.** Single-target accuracy in Experiment 2A is shown in Table 2. There were no significant effects (all  $F_s \leq 2$ ,  $ps > .11$ ). Overall, single-target

**Table 2**  
Accuracy Scores in Experiment 2 As a Function of Number of Targets, Spatial Dynamics of the Display, and Lag Relative to the First Target

No. Targets	Spatial Dynamics															
	Experiment 2A							Experiment 2B								
	Same-Stream Standard			Same-Stream Control				Different-Stream Switch			Same-Stream Standard			Different-Stream Cued Switch		
	Lag 1	Lag 2	Lag 3	Lag 7	Lag 1	Lag 2	Lag 3	Lag 7	Lag 1	Lag 2	Lag 3	Lag 7	Lag 1	Lag 2	Lag 3	Lag 7
Single target	.97	.93	.97	.91	.88	.95	.96	.92	.97	.93	.97	.91	.86	.88	.87	.89
Dual target, T1	.91	.95	.94	.94	.90	.94	.95	.95	.92	.93	.90	.93	.89	.79	.75	.79
Dual target, T2	.95	.82	.82	.90	.91	.82	.82	.90	.63	.65	.69	.80	.89	.78	.75	.74
Net AB	-.02	-.11	-.15	.01	.03	-.13	-.14	-.02	-.34	-.28	-.28	-.11	.01	-.09	-.12	-.08

Note—T1, first target; T2, second target; AB, attentional blink.

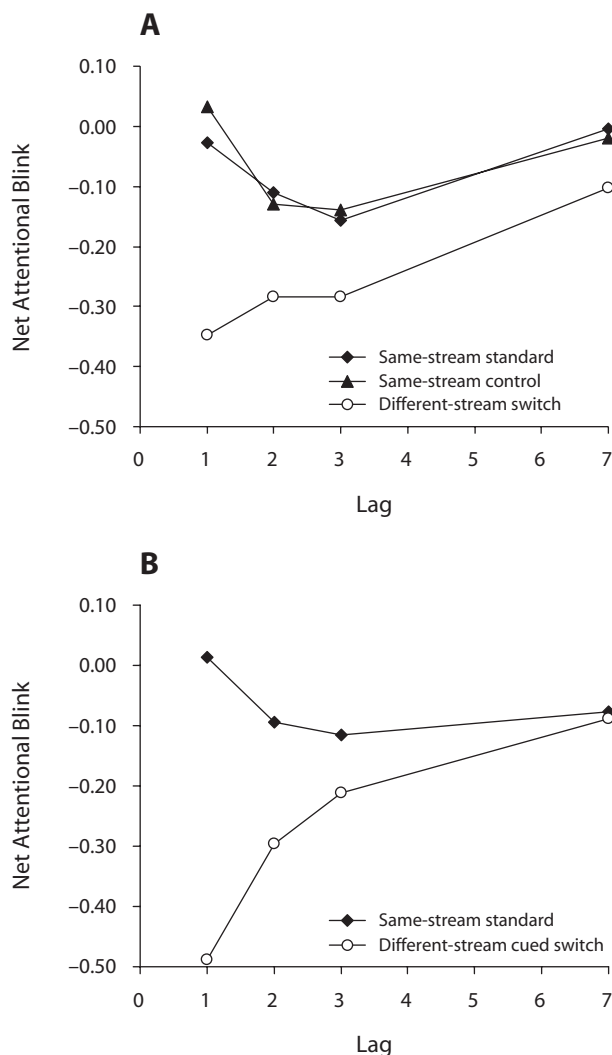
performance was high at 94% and stable across dynamics and lags. No single-target trials were included in Experiment 2B.

**Dual-target trials, T1.** T1 accuracy in the dual-target conditions is also shown in Table 2. In Experiment 2A, there was a main effect of lag [ $F(3,42) = 3.23, MS_e = .003, p < .05$ ]. In Experiment 2B, there was a trend toward the same effect of lag [ $F(3,27) = 2.69, MS_e = .002, p = .066$ ]. As in Experiment 1, T1 performance was, overall, somewhat worse for lag 1.

**Dual-target trials, T2.** In Experiment 2A, as in Experiment 1, the net AB was calculated by first subtracting the single-target condition. These data are shown in Figure 3A (as well as Table 2). There was a significant main effect of spatial dynamics [ $F(1,14) = 14.664, MS_e = .066, p = .002$ ] and lag [ $F(3,42) = 4.382, MS_e = .025, p = .019$ ]. Overall, performance improved with lag and was better in both same-stream conditions than in the different-stream condition. Important for the present argument, the interaction between spatial dynamics and lag was significant [ $F(3,42) = 6.691, MS_e = .079, p = .001$ ]. Figure 3A suggests that the source of this interaction was the lack of lag 1 sparing in the switch condition. To test specifically for this, the same ANOVA was conducted, but now with only lags 1 (where sparing would be expected to be maximal) and 3 (where the blink was maximal). This again showed a significant interaction between spatial dynamics and lag [ $F(1,14) = 11.727, MS_e = .012, p = .004$ ].

In Experiment 2B, the cue jumped from the T1 stream to the T2 stream, after the presentation of T1. A pattern similar to that in Experiment 2A emerged from Experiment 2B, as is shown in Figure 3B. Because Experiment 2A had revealed constant performance across lags in the single-target condition, we decided not include this condition in the present experiment. Instead, net AB values were calculated by subtracting the average T1 performance (across lags, which was comparable to single-target performance in Experiment 2A) from T2 performance (on each lag). Again, there were main effects of spatial dynamics [ $F(1,9) = 9.040, MS_e = .031, p = .015$ ] and lag [ $F(3,27) = 3.395, MS_e = .018, p = .032$ ]. Overall, performance was better in the same-stream condition and improved with lag. Importantly, the interaction between these factors again proved significant [ $F(3,27) = 11.265, MS_e = .028, p = .001$ ]. Figure 3B shows that there was no lag 1 sparing in the cued switch condition. Thus, even a cued switch was accompanied by a cost, probably reflecting the difficulty observers have with disengaging from the location of the still relevant T1 (which obviously did not move with the cue). Work by Dell'Acqua et al. (2006) has shown that a relevant T1 induces larger switch costs than does a T1 that can be disregarded. What is more, performance at lag 1 in the cued switch condition appeared to be even worse than that in the uncued switch condition in Experiment 2A. Although this was not significant ( $p = .12$ ), it may be that the cue, besides having informative value, also has a detrimental effect in that it may partially mask the target (e.g., Averbach & Coriell, 1961).

However, note that the jumped cue did, in the end, appear to aid performance at later lags. Unlike in Experi-



**Figure 3.** (A) Net attentional blink values for the second target (T2) conditioned on correct first target (T1) report as a function of lag in Experiment 2A. (B) Net attentional blink values for T2 conditioned on correct T1 report as a function of lag in Experiment 2B.

ment 2A, in which, even at later lags, different-stream performance remained inferior to same-stream performance, in Experiment 2B, different stream performance eventually reached the level of same-stream performance. In any case, this recovery from the switch was not rapid enough to allow for lag 1 sparing.

### GENERAL DISCUSSION

This study was motivated by the, so far, very suggestive but, at the same time, still inconclusive evidence that the AB is a nonspatial phenomenon. Much of this evidence has come from paradigms in which observers were required to switch from one stream to another. As we found in our Experiment 2 here, such switching leads to impairments in T2 report, consistent with an AB. Yet, at the same time, one of the hallmarks of the AB, lag 1 sparing, dis-

appears. This lack of lag 1 sparing is likely to be caused by spatial switch costs, but then, such costs might also explain the AB-like pattern itself. Thus, to further test the spatial nature of the AB, Experiment 1 employed a novel method in which attention was made to move continuously across an entire array of streams. We argued that this way, attention is already in motion, and switch costs should be reduced or absent. The results showed that lag 1 sparing returned but, at the same time, there was still an AB-like pattern. With lag 1 sparing in place, this blink-like pattern cannot be explained through spatial switch costs and, thus, reflects a true AB. We therefore conclude that the AB is indeed nonspatial, or *central*, in nature, as has been proposed within many theories (Bowman & Wyble, 2007; Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Shapiro et al., 1994).

An exception is the recent boost-and-bounce theory proposed by Olivers and Meeter (2008). They argued that the AB and lag 1 sparing are not independent but intrinsically related phenomena. According to boost-and-bounce theory, T1 triggers a rapid but transient attentional enhancement (the *boost*), which exerts its maximum effect around 100 msec later, when the post-T1 item has appeared. When this item is another target, lag 1 sparing is found. In contrast, when it is a distractor, this distractor will be accidentally enhanced. Because the task requires the observer to filter out distractors, such a strong distractor results in a strong inhibitory response, which is then measured as an AB. What is relevant for the present discussion is that both the boost and the bounce are thought to be partially location specific. That is, the attentional enhancement and inhibition are thought to be applied to the spatial source of the triggering event. This appears to be inconsistent with the present findings, which generated no evidence for spatial specificity. However, the theory may be amended in several ways. First, the enhancement and inhibition may be applied not (or not only) to location but to feature representations of the triggering item. For example, if an item is black, black may become temporarily enhanced or suppressed. Likewise, its shape features may become modulated, thus affecting later items sharing the same features. More generally, the inhibition may be applied to gate neurons governing the access to working memory, which are flexibly assigned to the target and distractor representations currently relevant for the task. A second possibility is that the boost and the bounce move along with spatial attention. If we conceive of spatial attention as a pointer mechanism, indexing important events in space, the boost and bounce may feed back to whatever attention is currently pointing to, even when attention is moving. Further studies are necessary to unfold such mechanisms.

Another important conclusion from this study is that performance costs caused by spatial switches should be dissociated from performance costs caused by the AB proper (see also Juola et al., 2004; Visser, Bischof, & Di Lollo, 1999). This would imply that investigators need to take care not to attribute such switch costs to the AB itself. We point out that the same argument may apply to task switches. Many AB studies involve two different

tasks for T1 and T2, in terms of both the stimulus properties the observer should look out for and the responses he or she should generate. Such task switches result in their own costs that may well add to the AB (Juola et al., 2004; Visser, Bischof, & Di Lollo, 1999). The interesting thing about the AB is that it occurs even when T1 and T2 are drawn from the same stimulus set and require the same type of response (e.g., Chun & Potter, 1995).

Finally, the present study confirms and extends earlier work by Jefferies et al. (2007), who found a complete AB, including considerable lag 1 sparing, across multiple locations when participants had no preknowledge on the location of T1. Jefferies et al. argued that the uncertainty of T1's location led observers to adopt a wider attentional focus, so that T2 could often pass through (at lag 1) regardless of its location. When participants have advance knowledge of T1, the gate will narrowly focus on the T1 stream, at the expense of a later T2. Although we adhere to Jefferies et al.'s conclusion, there is the remote possibility that the return of lag 1 sparing in their spatial uncertainty condition was due not to the lack of a switch, but to some other mechanism related to the uncertainty itself. For example, if one believes that lag 1 sparing is the result of T2's hitchhiking on T1 processing, the uncertainty may have led to overall extended T1 processing and, thus, an extended opportunity for T2 to join in. In our present study, the observers had perfect knowledge about T1's position in all the conditions (it was always in the 10th stream), yet lag 1 sparing did occur across different streams when attention was continuously moving from left to right. This means that uncertainty per se is not the crucial factor and that Jefferies et al. were indeed correct to attribute their results to different spatial distributions of attention.<sup>1</sup>

In conclusion, it appears then that when it comes to the reduction of spatial switch costs in multistream experiments, there are multiple means to the same end. One is widening of the attentional field through uncertainty, and another is making use of attentional momentum when it is moving across the display. The minimization of spatial switch costs is required to verify that an AB deficit across space is authentic. Both methods result in lag 1 sparing across multiple locations, as well as an AB. The important theoretical implication then is that neither the AB nor the lag 1 sparing deficit is location specific. They evidently occur when target stimuli are distributed across space.

#### AUTHOR NOTE

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#### REFERENCES

AKYÜREK, E. G., TOFFANIN, P., & HOMMEL, B. (2008). Adaptive control of event integration. *Journal of Experimental Psychology: Human Perception & Performance*, *34*, 569-577.

- AVERBACH, E., & CORIELL, A. S. (1961). Short-term memory in vision. *Bell System Technical Journal*, *40*, 309-328.
- BARRIOPEYRO, M. I., & BOTELLA, J. (1998). New evidence for the zoom lens model using the RSVP technique. *Perception & Psychophysics*, *60*, 1406-1414.
- BOWMAN, H., & WYBLE, B. (2007). The simultaneous type, serial token model of temporal attention and working memory. *Psychological Review*, *114*, 38-70.
- CHUN, M. M., & POTTER, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception & Performance*, *21*, 109-127.
- DELL'ACQUA, R., SESSA, P., JOLICEUR, P., & ROBITAILLE, N. (2006). Spatial attention freezes during the attentional blink. *Psychophysiology*, *43*, 394-400.
- DI LOLLO, V., KAWAHARA, J., GHORASHI, S. M. S., & ENNS, J. T. (2005). The attentional blink: Resource depletion or temporary loss of control? *Psychological Research*, *69*, 191-200.
- JEFFERIES, L. N., & DI LOLLO, V. (2009). Linear changes in the spatial extent of the focus of attention across time. *Journal of Experimental Psychology: Human Perception & Performance*, *35*, 1020-1031.
- JEFFERIES, L. N., GHORASHI, S., KAWAHARA, J., & DI LOLLO, V. (2007). Ignorance is bliss: The role of observer expectation in dynamic spatial tuning of the attentional focus. *Perception & Psychophysics*, *69*, 1162-1174.
- JOLICEUR, P., & DELL'ACQUA, R. (1998). The demonstration of short-term consolidation. *Cognitive Psychology*, *32*, 138-202.
- JUOLA, J. F., BOTELLA, J., & PALACIOS, A. (2004). Task- and location-switching effects on visual attention. *Perception & Psychophysics*, *66*, 1303-1317.
- KRISTJÁNSSON, Á., & NAKAYAMA, K. (2002). The attentional blink in space and time. *Vision Research*, *42*, 2039-2050.
- MACKEY, A., & JUOLA, J. F. (2007). Are spatial and temporal attention independent? *Perception & Psychophysics*, *69*, 972-979.
- MARTENS, S., ELMALLAH, K., LONDON, R., & JOHNSON, A. (2006). Cuing and probability effects on the P3 and the AB. *Acta Psychologica*, *123*, 204-218.
- MARTENS, S., & JOHNSON, A. (2005). Timing attention: Cuing target onset interval attenuates the attentional blink. *Memory & Cognition*, *33*, 234-240.
- NIJEUWENHUIS, S., GILZENRAT, M. S., HOLMES, B. D., & COHEN, J. D. (2005). The role of the locus coeruleus in mediating the attentional blink: A neurocomputational theory. *Journal of Experimental Psychology: General*, *134*, 291-307.
- NIJEUWENSTEIN, M. R., & POTTER, M. C. (2006). Temporal limits of selection and memory encoding: A comparison of whole versus partial report in rapid serial visual presentation. *Psychological Science*, *17*, 471-475.
- OLIVERS, C. N. L. (2004). Blink and shrink: The effect of the attentional blink on spatial processing. *Journal of Experimental Psychology: Human Perception & Performance*, *30*, 613-631.
- OLIVERS, C. N. L. (2007). The time course of attention: It's better than we thought. *Current Directions in Psychological Science*, *16*, 11-15.
- OLIVERS, C. N. L., & MEETER, M. (2008). A boost and bounce theory of temporal attention. *Psychological Review*, *115*, 836-863.
- OLIVERS, C. N. L., VAN DER STIGCHEL, S., & HULLEMAN, J. (2007). Spreading the sparing: Against a limited-capacity account of the attentional blink. *Psychological Research*, *71*, 126-139.
- PETERSON, M. S., & JUOLA, J. F. (2000). Evidence for distinct attentional bottlenecks in attention switching and attentional blink tasks. *Journal of General Psychology*, *127*, 6-26.
- POTTER, M. C., DELL'ACQUA, R., PESCIARELLI, F., JOB, R., PERESSOTTI, F., & O'CONNOR, D. H. (2005). Bidirectional semantic priming in the attentional blink. *Psychonomic Bulletin & Review*, *12*, 460-465.
- POTTER, M. C., STAUB, A., & O'CONNOR, D. H. (2002). The time course of competition for attention: Attention is initially labile. *Journal of Experimental Psychology: Human Perception & Performance*, *28*, 1149-1162.
- PRATT, J., SPALEK, T., & BRADSHAW, F. (1999). The time to detect targets at inhibited and noninhibited locations: Preliminary evidence for attentional momentum. *Journal of Experimental Psychology: Human Perception & Performance*, *25*, 730-746.



- PYLYSHYN, Z., & STORM, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision*, **3**, 179-197.
- RAYMOND, J. E., SHAPIRO, K. L., & ARNELL, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception & Performance*, **18**, 849-860.
- REEVES, A., & SPERLING, G. (1986). Attention gating in short-term visual memory. *Psychological Review*, **93**, 180-206.
- SHAPIRO, K. L., RAYMOND, J. E., & ARNELL, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception & Performance*, **20**, 357-371.
- SHIH, S.-I. (2000). Recall of two visual targets embedded in RSVP streams of distractors depends on their temporal and spatial relationship. *Perception & Psychophysics*, **62**, 1348-1355.
- SNYDER, J. J., SCHMIDT, W. C., & KINGSTONE, A. (2001). Attentional momentum does not underlie the inhibition of return. *Journal of Experimental Psychology: Human Perception & Performance*, **27**, 1420-1432.
- SPERLING, G., & WEICHELGARTNER, E. (1995). Episodic theory of the dynamics of spatial attention. *Psychological Review*, **102**, 503-532.
- VISSER, T. A. W., BISCHOF, W. F., & DI LOLLO, V. (1999). Attentional switching in spatial and nonspatial domains: Evidence from the attentional blink. *Psychological Bulletin*, **125**, 458-469.
- VISSER, T. A. W., ZUVIC, S. M., BISCHOF, W. F., & DI LOLLO, V. (1999). The attentional blink with targets in different spatial locations. *Psychonomic Bulletin & Review*, **6**, 432-436.
- WEICHELGARTNER, E., & SPERLING, G. (1987). Dynamics of automatic and controlled visual attention. *Science*, **238**, 778-780.

#### NOTE

1. Note that this continuous movement may well have had the consequence that attention was more distributed. That is, not only was it continuously moving, but also it was somewhat skewed in the direction of motion. This would then have the same effect as the distributed attention induced in Jefferies et al.'s (2007) study. Our point is not that such distributed attention did not occur or would not have an effect. Our point is that uncertainty per se may have contributed in ways other than intended.

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