

Individual Differences in the Attentional Blink:  
The Important Role of Irrelevant Information

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Abstract

A well-established phenomenon in the study of attention is the attentional blink (AB): A deficit in reporting the second of two targets when it occurs 200-500 ms after the first. Although the effect has been shown to be robust in a wide variety of task conditions, we recently reported that some individuals show little or no AB, and presented psychophysiological evidence that target processing differs in non-blinkers (who do not show an AB) and blinkers (who do show an AB). Here we present evidence that the level of distractor processing and subsequent interference with target identification processes also differs between the two groups. In one task, two masked targets were centrally presented at varying temporal intervals, with or without additional distractors. In a second task, the masked targets were presented eccentrically, with or without the presence of a central sequential stream of the task-irrelevant distractors. In both cases, the presence of distractors led to an increased AB magnitude in blinkers, whereas performance for non-blinkers remained relatively unaffected. The results thus support the hypothesis that non-blinkers are more efficient in ignoring irrelevant information than blinkers are.

Keywords: Attentional blink, individual differences, distractor interference, attentional capture, contingent capture, attentional selection, visual attention.

### Individual Differences in the Attentional Blink:

#### The Important Role of Irrelevant Information

To illustrate the concept of attention, psychology students are often shown a short movie clip, available on the internet. The movie features two teams, one dressed in white, the other in black, each throwing a ball. Halfway the movie clip a man in a black gorilla suit walks into view from the right side of the screen, ruffles his chest in the middle of the screen, and walks out of view on the other side of the screen. Intriguingly, when instructed to count the number of times the white team plays the ball to one of its members, the majority of the audience fails to notice the black gorilla. When told about the gorilla and instructed to direct attention to the black team while watching the clip again, most people can hardly believe that it is the same movie clip.

There are many other examples showing that the human mind is severely limited in processing concurrent information at a conscious level of awareness (see, e.g. Raymond, Shapiro, & Arnell, 1992; Rensink, 2002; Vogel, Woodman, & Luck; 2006). The movie clip elegantly shows that attention acts as a filter, selecting relevant information and suppressing irrelevant information. As only a fraction of the information that is present in the environment can be selected for further, conscious processing, it is important to select only that information that is most relevant to current goals and intentions. However, not everyone is equally capable of selecting relevant from irrelevant information (illustrated by the students who do notice the gorilla), and large individual differences exist in the amount of concurrently presented information that people can become aware of.

Temporal restrictions in the ability to identify relevant information presented amongst irrelevant information are clearly revealed in attentional blink (AB) studies (Raymond, Shapiro, & Arnell, 1992). Participants often fail to report the second (T2) of two targets when it occurs 200-500 ms after the first (T1). This remarkable deficit, referred to as the AB, has received much interest in the past 15 years and has been replicated in hundreds of experiments using a wide variety of task conditions. The paradigm typically consists of visually presenting a stream of non-target items at a rate of about 11 items per second. Among these distractors (e.g., digits), two targets (e.g., letters) are embedded which subjects are required to identify. By systematically varying the number of distractors (and thus the time interval) between the two targets, the magnitude and time-course of the AB can be measured. Combined with modern brain-imaging techniques, the AB paradigm has proven not only to be an effective tool to study the time-course of attention and memory consolidation within and across sensory modalities (e.g., Duncan, Martens, & Ward, 1997), it also provides researchers with a unique tool to study human consciousness (e.g., Sergent, Baillet, & Dehaene, 2005).

Although the AB is generally assumed to reflect a fundamental limitation in information processing, we recently reported that some individuals do not show an AB, and presented psychophysiological evidence that target processing differs in “blinkers” (who show a strong AB) and “non-blinkers” (who show little or no AB; Martens, Munneke, Smid, & Johnson, 2006). EEG activity for both groups was recorded during the execution of a task in which two visually presented letters had to be detected in a sequential stream of digit distractors. Differences in parietal brain activity were found suggesting that non-blinkers are quicker to consolidate information than are blinkers.

Differences in frontal brain activity were also found, such that non-blinkers showed a larger difference between target and distractor activation than did blinkers.

Germane to the current paper, on trials during which only distractors were presented, blinkers showed more prefrontal activity than non-blinkers in response to each distractor. This relatively high level of activity in blinkers could indicate that blinkers directed more attention to each distractor than non-blinkers did (see, e.g., Spitzer, Desimone, & Moran, 1988). In other words, blinkers may be less able to ignore distractors than non-blinkers. To test this hypothesis, we used two AB tasks developed by Visser, Bischof, & Di Lollo (2004; Experiments 1A and 1B). In Experiment 1, a group of blinkers and a group of non-blinkers were asked to identify two target letters embedded in a rapid serial visual presentation (RSVP) stream of central distractor digits. In a second condition, both groups were asked to identify the targets in the absence of distractors. The same conditions were tested in Experiment 2, with distractors - if present - still being presented centrally, but with targets presented eccentrically.

Visser et al. (2004) showed that the presence of central distractors affects the magnitude and the time course of the AB deficit, even when targets were presented eccentrically. The novel aspect of the current study over that of Visser et al. is the inclusion of a non-blinker group, allowing a direct comparison between individual levels of AB magnitude and the amount of distractor interference. If it is true that blinkers direct more attention to distractors than non-blinkers do, the presence or absence of distractors should have a larger impact on the performance of blinkers than of non-blinkers.

## Experiment 1

Whereas an AB can be observed in most people, it has been shown that some individuals, referred to as non-blinkers, show little or no AB in a visual task requiring the identification of two target letters embedded in a stream of digit distractors (e.g., Martens, Munneke, et al., 2006; Martens, Johnson, Bolle, & Borst, submitted; Martens & Johnson, submitted). Given Visser et al.'s finding (2004) that the presence of distractors can substantially increase the AB deficit, Experiment 1 was set-up to test whether the presence of distractors also affects target identification in non-blinkers, and if so, whether the interfering effect is of similar magnitude as in blinkers.

### Method

Participants. On the basis of previous performance in AB experiments in our laboratory in which two targets had to be identified amongst an RSVP stream of distractors (e.g., Martens, Elmallah, London, & Jonson, 2006; Martens & Johnson, 2005; Nieuwenstein, Johnson, Kanai, & Martens, in press; Martens & Johnson, submitted; Martens, Bolle, Borst, & Johnson, submitted), 28 participants were selected. AB magnitude was calculated as the percentage of decrement in T2 performance (given that T1 was correctly identified) relative to T1 performance for trials during which T2 was presented as the third item after T1 (lag 3; the lag during which an AB is typically at maximum) according to the following formula:

$$\left( \frac{T1_{Lag3} - T2 | T1_{Lag3}}{T1_{Lag3}} \right) * 100\%$$

Thirteen volunteers (aged 19 to 27, mean = 23.0) had previously shown (in at least two experiments) an AB magnitude of 10% or less (mean = 4.2%, range = -2.1 to 9.0) and were assigned to a non-blinker group, 15 participants (aged 18-26, mean = 21.0 years) had previously shown an AB magnitude of at least 35% (mean = 63.3%, range =

36.7 to 95.9%) and were assigned to a blinker group. All participants were recruited from the University of Groningen community, and had normal or corrected-to-normal visual acuity. Informed consent was obtained prior to the experiment and participants received payment of € 6.

Stimuli and apparatus. The generation of stimuli and the collection of responses were controlled using E-prime 1.2 software (Schneider, Eschmann, & Zuccolotto, 2002; Stahl, 2006) running under Windows XP on a PC with a 2.8 Ghz processor. Stimuli consisted of digits (0 to 9) and uppercase letters (excluding I, O, Q, and Z due to their similarity to the digits 1, 0, 2, and 7) and were presented in black ( $2 \text{ cd/m}^2$ ) on a white background ( $88 \text{ cd/m}^2$ ) in a 32-point Courier New font on a 17-in. CRT monitor. The stimuli subtended  $\sim 1^\circ$  by  $1^\circ$  of visual angle at a viewing distance of approximately 60 cm.

Procedure. The experiment consisted of two experimental blocks of 144 trials each. Before each experimental block a practice block of 15 trials was completed. A short break was allowed between the blocks. In each block, one of two conditions was tested, and the order of the two experimental conditions (with or without distractors) was counterbalanced between participants.

Before each trial, a fixation cross was presented in the middle of the screen with a message at the bottom of the screen, prompting participants to press the space bar to initiate the trial. When the space bar was pressed the screen was cleared. In the condition with distractors, 500 ms later the RSVP stimulus stream appeared in the middle of the screen, consisting of 20 sequentially presented items. Each stimulus appeared for 30 ms followed by a blank inter stimulus interval of 70 ms. The sequential position of T1 varied

randomly between position 6 to 11. T2 was the first, third, or seventh item following T1 (i.e., it was presented at lag 1, 3, or 7, respectively) and was always followed by at least two distractors. Target letters were randomly selected with the constraint that T1 and T2 were always different letters. Digit distractors were randomly selected with the constraint that no single digit was presented twice in succession. After the stream was presented, participants were prompted by a message at the bottom of the screen to type the letters they had seen using the corresponding keys on the computer keyboard. Participants were instructed to take sufficient time in making their responses to ensure that typing errors were not made. Participants were encouraged to type in their responses in the order in which the letters had been presented, but responses were accepted and counted correct in either order.

In the condition without distractors, the procedure was the same except for the following. After participants had pressed the space bar to initiate a trial, the screen was cleared and T1 was presented after 500 to 1000 ms. Again, T2 was presented at a lag of 1, 3, or 7. No distractors were presented except for the ones following each target (at a stimulus onset asynchrony of 100 ms), thereby functioning as masks<sup>1</sup>. After the last mask was presented, the screen remained empty for another 100-1200 ms, after which participants were again prompted on the screen to give their responses. Participants completed the task in approximately 45 minutes.

### Results and Discussion

Where appropriate, Greenhouse-Geisser-corrected *p* values are reported. Figure 1 shows T1 performance with or without distractors as a function of lag for non-blinkers and blinkers, respectively. Mean T1 performance for the non-blinkers was 97.4% without

distractors, and 96.2% with distractors, whereas for the blinkers mean T1 performance was 95.65% without distractors and 90.0% with distractors. A mixed analysis of variance (ANOVA) with group (non-blinkers or blinkers) as a between-subjects factor and condition (with or without distractors) and lag (1, 3, or 7) as within-subjects factors revealed significant effects of group,  $F(1, 26) = 5.71$ ,  $MSE = 117.33$ ,  $p = .02$ ,  $\eta^2_p = .18$ , condition,  $F(1, 26) = 26.37$ ,  $MSE = 18.31$ ,  $p < .001$ ,  $\eta^2_p = .50$ , and lag,  $F(2, 52) = 21.02$ ,  $MSE = 27.63$ ,  $p < .001$ ,  $\eta^2_p = .45$ . In addition, a significant Condition  $\times$  Group interaction,  $F(1, 26) = 11.51$ ,  $MSE = 18.31$ ,  $p = .002$ ,  $\eta^2_p = .31$ , Lag  $\times$  Group interaction,  $F(2, 52) = 6.07$ ,  $MSE = 27.63$ ,  $p = .008$ ,  $\eta^2_p = .19$ , and Condition  $\times$  Lag interaction,  $F(2, 52) = 6.88$ ,  $MSE = 17.37$ ,  $p = .009$ ,  $\eta^2_p = .21$ , were found. The Condition  $\times$  Group interaction indicates that the interfering effect of distractors on T1 identification is stronger for blinkers than for non-blinkers. The Lag  $\times$  Condition interaction indicates that this interference effect is strongest at lag 1, possibly reflecting increased competition between T1 and T2 due to the presence of distractors. To test whether there was a difference between the two groups to identify T1 at lags 3 and 7, we restricted the analysis on T1 data to lags 3 and 7 only, which still revealed a significant effect of condition,  $F(1, 26) = 11.10$ ,  $MSE = 7.48$ ,  $p = .003$ ,  $\eta^2_p = .30$ , and a significant Condition  $\times$  Group interaction,  $F(1, 26) = 6.70$ ,  $MSE = 7.48$ ,  $p = .016$ ,  $\eta^2_p = .21$ , but no effects of group ( $p = .11$ ), lag ( $p = .25$ ), or any other interactions ( $ps > .30$ ). These results suggest that although the distractors interfered more with T1 identification for the blinkers than for the non-blinkers, there was no difference in overall task difficulty between the two groups.

Figure 2 shows T2 performance, given that T1 was identified correctly, with or without distractors as a function of lag for non-blinkers and blinkers, respectively. A mixed ANOVA with group (non-blinkers or blinkers) as a between-subjects factor and condition (with or without distractors) and lag (1, 3, or 7) as within-subjects factors revealed significant effects of group,  $F(1, 26) = 27.42$ ,  $MSE = 282.36$ ,  $p < .001$ ,  $\eta^2_p = .51$ , condition,  $F(1, 26) = 45.33$ ,  $MSE = 72.29$ ,  $p < .001$ ,  $\eta^2_p = .64$ , and lag,  $F(2, 52) = 45.50$ ,  $MSE = 100.06$ ,  $p < .001$ ,  $\eta^2_p = .64$ . In addition, a significant Condition  $\times$  Group interaction,  $F(1, 26) = 8.59$ ,  $MSE = 72.29$ ,  $p = .007$ ,  $\eta^2_p = .25$ , Lag  $\times$  Group interaction,  $F(2, 52) = 20.59$ ,  $MSE = 100.06$ ,  $p < .001$ ,  $\eta^2_p = .44$ , Condition  $\times$  Lag interaction,  $F(2, 52) = 31.11$ ,  $MSE = 51.26$ ,  $p < .001$ ,  $\eta^2_p = .55$ , and Condition  $\times$  Lag  $\times$  Group interaction,  $F(2, 52) = 8.74$ ,  $MSE = 51.26$ ,  $p = .001$ ,  $\eta^2_p = .25$ , were found.

The results indicate that the AB was substantially larger in blinkers than non-blinkers when distractors were present. Using the formula specified in the method section, individual AB magnitudes were computed for each condition. The blinkers' AB magnitude increased from 17.1% when distractors were absent to 46.1% when distractors were present,  $t(14) = 4.81$ ,  $SE = 6.04$ ,  $p < .001$ . Although the non-blinkers' AB magnitude was also larger when distractors were present (10.2%) than when they were absent (.5%),  $t(12) = 5.21$ ,  $SE = 1.86$ ,  $p < .001$ , overall T2 performance in the condition with distractors (93.3%) remained numerically higher than that of the blinkers in the condition without distractors (88.6%), although this difference was not significant ( $p = .18$ ). Finally, we checked the intra-individual stability of performance in the condition with distractors. Spearman-Brown prophecy coefficients were .89 for T1, .95 for T2, and .87 for AB magnitude, reflecting stable within-subject performance.

The results from the blinkers replicate findings previously reported by Visser et al. (2004), who also found that the presence of distractors substantially reduced identification accuracy for both T1 and T2. Extending Visser et al.'s results, we found that the distractor interference effect was much smaller in non-blinkers, consistent with the idea that blinkers may direct more attention to each distractor than non-blinkers do (Martens, Munneke, et al., 2006). Apparently, non-blinkers are better able to ignore distractors than blinkers, thereby keeping any interference effects to a minimum level.

Noted by Visser et al. (2004), the distractor-induced interference experienced by blinkers could influence performance in at least two ways. Visser et al. proposed that distractors could interfere with target identification through contingent capture, a process by which an irrelevant stimulus that shares target features captures attention, thereby slowing target processing and reducing identification accuracy (see e.g., Folk, Remington, & Johnston, 1992; Ghorashi, Zuvic, Visser, & Di Lollo, 2003). Originally pointed out by Ward, Duncan, and Shapiro (1997), another way by which distractors may hamper target identification is forward masking. In this case, interference might occur because the targets are masked by both the preceding and subsequent distractor in the stream, causing both forward and backward masking. However, Visser et al. (2004; Experiment 1A) showed that distractors could even interfere with target identification processes when targets and distractors were presented in different spatial locations, ruling forward masking out as the main source of interference (also see Breitmeyer, Ehrenstein, Pritchard, Hiscock, & Crisan, 1999). Experiment 2 was set up using a similar paradigm as in Visser et al.'s study to replicate their results with blinkers and to investigate possible

spatial contingent capture effects by distractors in the absence of forward masking in non-blinkers.

## Experiment 2

The aim of Experiment 2 was to investigate the interfering influence of distractors on target identification when targets and distractors are presented in different spatial locations. If the hypothesis is correct that blinkers tend to direct more attention to irrelevant distractors than non-blinkers do (Martens, Munneke, et al., 2006), an increased AB should occur for blinkers when distractors are present compared to when they are absent. In contrast, the presence of distractors is expected not to interfere much with non-blinkers' target identification accuracy.

### Method

Participants. The same volunteers as in Experiment 1 participated in this experiment<sup>2</sup> and received payment of € 6.

Stimuli and apparatus. The stimuli and apparatus were the same as in Experiment 1.

Procedure. The procedure was the same as in Experiment 1, with the following exceptions. In the condition with distractors, the fixation cross disappeared when participants initiated a trial by pressing the space bar. Five hundred ms later, the RSVP stream of 20 distractors was sequentially presented in the middle of the screen. T1 randomly appeared in one of four possible locations (left, right, above or below the fixation cross) at a distance of  $\sim 1^\circ$  from the center of the screen, 500 to 1000 ms after the onset of the stream. T2 was randomly presented in one of the remaining three locations, 100, 300, or 700 ms after the onset of T1, corresponding with lags 1, 3, or 7. Both targets

were masked by a single digit as in Experiment 1. As before, each stimulus was presented for 30 ms, followed by an inter stimulus interval of 70 ms. Each combination of T1 location, T2 location, and lag was presented equally often. The participants were instructed to maintain fixation on the distractor stream, but to ignore its contents as it would never contain a target.

For the condition without distractors, the procedure was the same except that no RSVP stream of distractors was presented. After participants had pressed the space bar to initiate the trial, the central fixation cross remained on the screen and T1 was presented 1000 to 1500 ms later. Participants completed the task in approximately 45 minutes.

### Results and Discussion

Initial analyses showed that the mean T1 accuracy in the condition with distractors was lower than 70% for one non-blinker and two blinkers. In order to obtain a reliable measure of T2/T1, we excluded these participants from further analyses. Figure 3 shows T1 performance with or without distractors as a function of lag for the remaining non-blinkers and blinkers. Mean T1 performance for the non-blinkers was 96.6% without distractors, and 95.3% with distractors, whereas for the blinkers mean T1 performance was 95.3% without distractors and 92.7% with distractors. A mixed ANOVA with group (non-blinkers or blinkers) as a between-subjects factor and condition (with or without distractors) and lag (1, 3, or 7) as within-subjects factors revealed significant effects of condition,  $F(1, 23) = 5.22$ ,  $MSE = 26.78$ ,  $p = .032$ ,  $\eta^2_p = .19$ , and lag,  $F(2, 46) = 21.94$ ,  $MSE = 6.75$ ,  $p < .001$ ,  $\eta^2_p = .49$ . The effect of group was not significant ( $p = .28$ ), and there were no significant interactions ( $ps > .43$ ). These results suggest that the task was of

equal difficulty for both groups, and that the interfering effect or spatial contingent capture of distractors on T1 identification was equally large for both groups.

Figure 4 shows T2 performance, given that T1 was identified correctly, with or without distractors as a function of lag for non-blinkers and blinkers, respectively. A mixed ANOVA with group (non-blinkers or blinkers) as a between-subjects factor and condition (with or without distractors) and lag (1, 3, or 7) as within-subjects factors revealed significant effects of group,  $F(1, 23) = 15.57$ ,  $MSE = 374.70$ ,  $p = .001$ ,  $\eta^2_p = .40$ , condition,  $F(1, 23) = 38.99$ ,  $MSE = 81.16$ ,  $p < .001$ ,  $\eta^2_p = .63$ , and lag,  $F(2, 46) = 33.35$ ,  $MSE = 69.59$ ,  $p < .001$ ,  $\eta^2_p = .59$ . In addition, a significant Condition  $\times$  Group interaction,  $F(1, 23) = 6.78$ ,  $MSE = 81.16$ ,  $p = .016$ ,  $\eta^2_p = .23$ , Lag  $\times$  Group interaction,  $F(2, 46) = 7.32$ ,  $MSE = 69.59$ ,  $p = .002$ ,  $\eta^2_p = .24$ , and Condition  $\times$  Lag interaction,  $F(2, 46) = 3.86$ ,  $MSE = 51.31$ ,  $p = .033$ ,  $\eta^2_p = .14$ , were found. The Condition  $\times$  Lag  $\times$  Group interaction was not significant ( $p = .65$ ).

The blinkers' AB magnitude increased from 10.1% when distractors were absent to 28.4% when distractors were present,  $t(12) = 6.04$ ,  $SE = 3.04$ ,  $p < .001$ . Although the non-blinkers' AB magnitude was also larger when distractors were present (8.4%) than when they were absent (0.5%),  $t(11) = 2.91$ ,  $SE = 2.73$ ,  $p = .014$ , overall T2 performance in the condition with distractors (90.8%) remained numerically higher than that of the blinkers in the condition without distractors (87.5%), although this difference was not significant ( $p = .28$ ). Finally, we checked the intra-individual stability of performance in the condition with distractors. Spearman-Brown prophecy coefficients were .83 for T1, .91 for T2, and .84 for AB magnitude, reflecting stable within-subject performance similar to that in Experiment 1.

Replicating Visser et al.'s findings, the results show that the presence of distractors interfered with the identification of both T1 and T2, even though the distractors were presented at a different location than the targets and participants were explicitly instructed to ignore them. Although the interference on T1 identification was similar for both groups, the interference on T2 was substantially greater for blinkers than for non-blinkers, which is consistent with the idea that blinkers are more susceptible to contingent capture by the distractors than non-blinkers are. In contrast to Experiment 1, forward masking can be ruled out in the current experiment as a plausible source of distractor interference, because the items in the RSVP stream were too far removed from the targets to act as effective masks. In Experiment 1, a Condition  $\times$  Group interaction was observed indicating that the interfering effect of distractors on T1 identification was stronger for blinkers than for non-blinkers. The fact that this interaction was not observed in Experiment 2 may suggest that in Experiment 1 T1 performance in blinkers suffered from more forward masking by distractors than T1 performance in non-blinkers.

### General Discussion

Martens, Munneke, et al. (2006) showed that there are large individual differences in the magnitude of the AB effect: Whereas most individuals show a large temporal deficit to identify a target when it is presented within 200-500 ms after a first target ('blinkers'), some individuals seem to have little or no problem to accurately identify both targets regardless of the temporal interval between the targets ('non-blinkers'). Visser et al. (2004) showed that the magnitude of the AB is substantially increased when the masked targets are embedded within an RSVP stream of irrelevant distractors. In the current study, a group of strong blinkers and a group of non-blinkers was tested with

similar tasks as those used by Visser et al., in order to address the question whether the target identification performance of non-blinkers is as much affected by the presence of distractors as that of blinkers.

In two experiments, two masked targets were presented at varying temporal intervals, in the presence or absence of a central RSVP stream of irrelevant distractors. Targets were either presented at the same central location as the distractors (Experiment 1), or in adjacent locations (Experiment 2). Overall T1 performance was similar for the two groups, which suggests that the task difficulty was equivalent for both blinkers and non-blinkers. However, large differences in T2 performance were observed, especially at lag 3, the temporal target interval during which the AB usually is at maximum. When distractors were present, non-blinkers showed a larger but still relatively small AB magnitude compared to the condition without distractors. In contrast, the blinkers showed an AB magnitude that was substantially larger when distractors were present than when they were absent, congruent to the findings reported by Visser et al. (2004). Importantly, Visser et al. (experiments 2-4) showed that increasing the similarity between targets and distractors resulted in an increased AB effect (also see Chun & Potter, 1995; Maki, Bussard, Lopez, & Digby, 2003), suggesting a causal link between the amount of distractor interference and AB magnitude.

One could argue that the lack of a strong AB effect in non-blinkers might be due to the fact that their performance was close to ceiling. To investigate this possibility, we recently conducted a control experiment (Martens, Johnson, Bolle, & Borst, submitted) requiring the identification of two target letters embedded in an RSVP stream of distractor digits similar to the distractor present condition of Experiment 1 presented

here. However, when the difficulty of visual targets was dynamically manipulated such that T1 accuracy remained below ceiling and was comparable with the level of T1 performance in blinkers, non-blinkers continued to show little or no AB effect. More specifically, whereas T1 performance under these conditions was 81.0% in non-blinkers, their AB magnitude was still only 5.9%. In comparison, when the difficulty of T1 was not manipulated, T1 performance was 95.2% for non-blinkers and 82.1% for blinkers, and AB magnitudes were 6.1% and 39.9%, respectively. These results suggest that the differences in AB magnitude between blinkers and non-blinkers cannot be explained by a ceiling effect or differences in task difficulty. Together with previous evidence provided by Martens, Munneke, et al. (2006, Experiment 2) showing no AB for non-blinkers and a large AB for blinkers under equivalent off-ceiling T1 performance levels, we are confident to conclude that the non-blinkers' lack of a strong AB effect observed in the current experiments was unlikely to be due to a ceiling effect.

(Individual) differences in target and distractor processing.

Taken together, our results suggest that individual differences in AB magnitude may stem from variability in resisting contingent capture by irrelevant stimuli. More specifically, data from the current experiments suggests that non-blinkers are better able to ignore distractors as well as masks (which were both digits) than blinkers are, indicated by the finding that T2 performance for blinkers and non-blinkers also differed when distractor digits were absent except for the single digits masking each target. This is in line with the EEG results reported by Martens, Munneke, et al. (2006), who reported less distractor-related prefrontal brain activity in non-blinkers than in blinkers. Also, an MEG study by Gross et al. (2004) with blinkers showed stronger desynchronization of

distractor-related activity within a fronto-parieto-temporal network on non-blink trials (when both targets were successfully identified) than on blink trials (when only the first target was successfully identified), suggesting that an AB was avoided when irrelevant distractors and masks were sufficiently suppressed.

When targets were presented, Martens, Munneke, et al. (2006) found non-blinkers to show significant bilateral frontal selection positivity (FSP) effects over the ventrolateral prefrontal cortex (VLPFC), an area associated with controlled selection and retrieval (Badre, Poldrack, Pare-Blagoev, Inslar, & Wagner, 2005; Courtney, Ungerleider, Keil, & Haxby, 1997; Passingham, 1993; Petrides, 1994; Rushworth, Nixon, Eacott, & Passingham, 1997), whereas blinkers only showed weak FSP effects over the left VLPFC in response to targets. The amount of target-related activity in the right VLPFC was found to correlate with individual AB magnitude. Using fMRI, such a correlation was also found by Hein, Alink, Kleinschmidt, and Müller (2007), who reported that strong blinkers tended to show less activity in the VLPFC.

The picture that emerges is that the VLPFC may play a crucial role in the selection of targets and the suppression of non-targets. The efficiency with which this is done may be the critical factor in determining whether an AB does or does not occur. Indeed, when the difficulty to distinguish between targets and distractors is increased, the amount of contingent attentional capture by distractors also increases, reflected by an enhanced AB effect (e.g., Chun & Potter, 1995; Maki, Bussard, Lopez, & Digby, 2003; Visser et al., 2004).

Implications for theories of the AB

Although the data presented here does not drive a distinction between general theories of the AB, it is nevertheless of interest to examine how theoretical models can encompass the present findings. Two leading theoretical models of the AB are the two-stage model, originally proposed by Chun and Potter (1995), and the interference model, proposed by Shapiro, Arnell, and Raymond (1997) and Shapiro, Raymond, and Arnell (1994). According to the two-stage model, stimuli are processed to the point of conceptual representation during the first high-capacity parallel processing stage. In the second, capacity-limited serial processing stage, representations are consolidated into a durable and reportable form. The AB arises when T1 consumes the majority of the Stage 2 processing capacity, preventing consolidation of T2. In the interference model, each item is compared to a target template during Stage 1 processing (cf. Duncan & Humphreys, 1989). Items meeting the target criteria (including for instance distractors that are in close proximity to the targets) are assigned a selection weight, and proceed to Stage 2, gaining entry into visual short-term memory (VSTM). The probability of successful selection for report from VSTM depends on the number and similarity of items in VSTM: The more items and the greater their similarity to each other, the greater the competition within VSTM and the lower the probability of correct target retrieval.

A major difference between the two-stage model of Chun and Potter (1995) and the interference model of Shapiro et al. (1994) is that the two-stage model assumes that T2 fails to reach working memory due to its vulnerability to interference or decay while still in Stage 1, whereas the interference model assumes that both T1 and T2 may reach VSTM (Stage 2), but that T2 may be lost due to interference with T1 or distractors.

To account for the finding of an increased AB due to the presence of distractors, Visser et al. (2004) proposed the input-filtering model, which is basically a modified version of the two-stage model. The main difference is an explicit filtering function assigned to the first processing stage, which in turn is quite similar to the target-matching process assumed by the interference model. In the input-filtering model, stimuli that match the setting of the input filter are tagged as potential targets, and are allowed access to Stage 2. Other stimuli are denied access to Stage 2, and therefore remain vulnerable to decay and interference by subsequent items. If distractors share many features with the targets, a distractor presented prior to a target is also likely to gain entry to Stage 2, delaying Stage 2 processing of the subsequent targets, resulting in decreased target identification performance and an increased AB magnitude. Visser et al. suggested that it may take less time to process and reject a distractor than to process and consolidate an actual target in stage 2, explaining why T1 (preceded by distractors only) is identified more often than T2 (preceded by T1 and distractors, thereby being vulnerable to interference or decay for a longer period), especially at the shorter lags.

When it is assumed that non-blinkers are better at distinguishing targets from non-targets at an early stage of processing, both the input-filter model and the interference model are able to account for the present results. In terms of an input-filter model, non-blinkers may program their input filters more strictly than blinkers do, allowing fewer distractors to access Stage 2, resulting in shorter delays for targets to be processed and consolidated. In the interference model, non-blinkers may assign relatively strong weights to each target and relatively weak weights to each distractor, thereby reducing the number of distractors that is allowed access to VSTM. The subsequent reduction in

competition between items within VSTM may allow sufficient resources to be available for faster consolidation and successful report of both targets.

### Conclusion

In summary, the results of our study show that the presence of distractors leads to spatial as well as nonspatial contingent attentional capture, resulting in decreased overall target identification performance and a substantially increased AB in blinkers. In contrast, although AB magnitude slightly increased, performance for non-blinkers remained relatively unaffected by the presence of task-irrelevant distractors. Compared to blinkers, non-blinkers are apparently better at ignoring irrelevant stimuli (including target masks), which is in line with previous reports of less distractor-related and more target-related frontal brain activity in non-blinkers (Martens, Munneke, et al., 2006). More research is clearly needed to determine whether non-blinkers and blinkers mainly differ in their ability to ignore irrelevant stimuli, or whether additional differences exist, reflected in other cognitive tasks (see e.g., Arnell, Howe, Joannis, & Klein, in press; Colzato, Spapé, Pannebakker, & Hommel, in press; Green & Bavelier, 2003; Martens, Johnson, Bolle, & Borst, submitted; Martens & Johnson, submitted). By showing that individual differences in AB magnitude may stem from variability in resisting contingent capture by irrelevant stimuli, we hope to be one step closer to answering the question why considerable attentional restrictions are usually observed in most people, and why such restrictions vary from trial to trial.

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Footnotes

<sup>1</sup>When T2 was presented at lag 1 no masking digit was presented after T1, as it was already masked by the presence of T2.

<sup>2</sup>Because we only have a limited number of non-blinkers in our database of volunteers who persistently show an absence of an AB, the non-blinkers from Experiment 1 were re-invited to participate in the Experiment 2. We also re-invited the same blinkers, so that if participation in Experiment 1 would have affected performance in any way, its effects would be equal for both groups of participants. As for the influence of training effects on the magnitude of the AB, Braun (1999) showed that the size of the AB is not attenuated when participants are given more training. We therefore think that the results of Experiment 2 would not be different if the experiment was run with new groups of blinkers and non-blinkers.

Figure captions

Figure 1. Mean percentage correct report of T1 in Experiment 1 with or without distractors as a function of lag, for non-blinkers and blinkers. Error bars reflect standard error of the mean.

Figure 2. Mean percentage correct report of T2 in Experiment 1, given correct report of T1, with or without distractors as a function of lag, for non-blinkers and blinkers. Error bars reflect standard error of the mean.

Figure 3. Mean percentage correct report of T1 in Experiment 2 with or without distractors as a function of lag, for non-blinkers and blinkers. Error bars reflect standard error of the mean.

Figure 4. Mean percentage correct report of T2 in Experiment 2, given correct report of T1, with or without distractors as a function of lag, for non-blinkers and blinkers. Error bars reflect standard error of the mean.

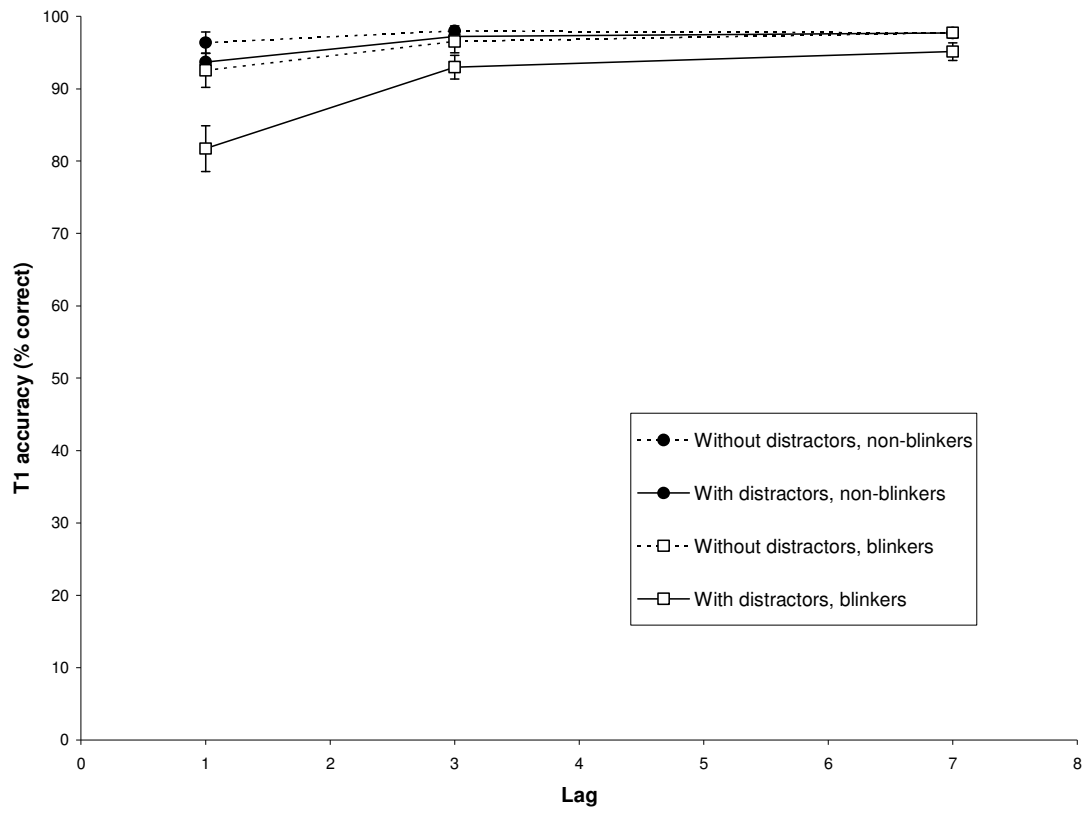


Figure 1

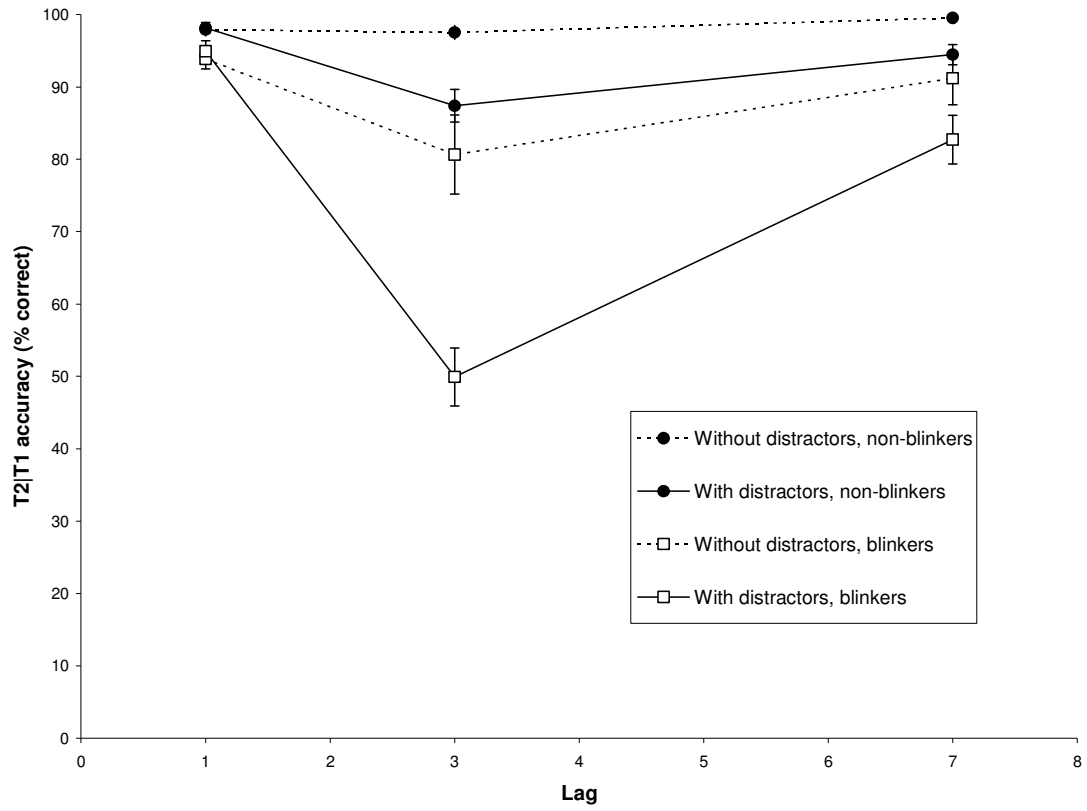


Figure 2

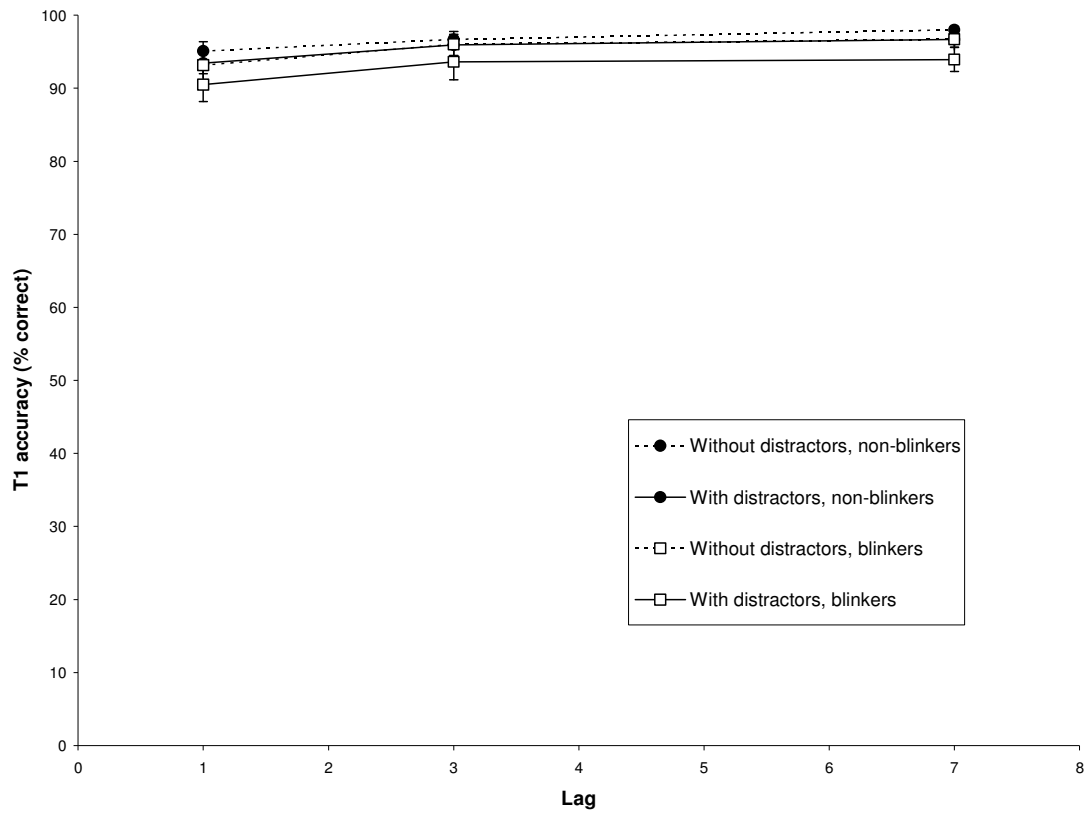


Figure 3

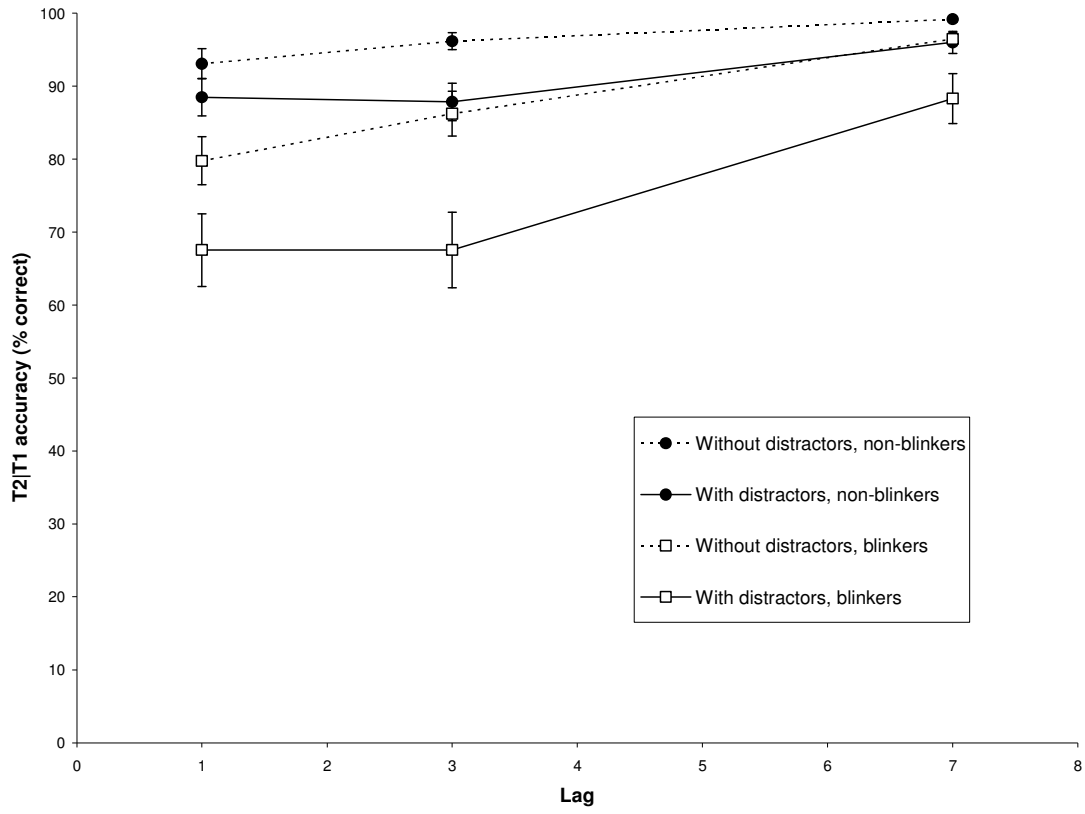


Figure 4