A Quick Visual Mind Can be a Slow Auditory Mind

Individual Differences in Attentional Selection Across Modalities

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Abstract. The human mind is severely limited in processing concurrent information at a conscious level of awareness. These temporal restrictions are clearly reflected in the attentional blink (AB), a deficit in reporting the second of two targets when it occurs 200–500 ms after the first. However, we recently reported that some individuals do not show a visual AB, and presented psychophysiological evidence that target processing differs between "blinkers" and "nonblinkers". Here, we present evidence that visual nonblinkers do show an auditory AB, which suggests that a major source of attentional restriction as reflected in the AB is likely to be modality-specific. In Experiment 3, we show that when the difficulty in identifying visual targets is increased, nonblinkers continue to show little or no visual AB, suggesting that the presence of an AB in the auditory but not in the visual modality is not due to a difference in task difficulty.

Keywords: attentional blink, auditory modality, visual modality, individual differences, selective attention

When several sources of information simultaneously require attention, limitations become apparent (see, e.g., Johnson & Proctor, 2004). For example, if you realize that your car navigation system is sending you in an unwanted direction, you may at that moment fail to see a crossing pedestrian. The human mind is clearly limited in its ability to process concurrent information at a conscious level of awareness.

Within the laboratory, temporal restrictions in the ability to identify two target stimuli have been extensively studied with the "attentional blink" paradigm. In this paradigm two targets, presented in a rapid serial visual presentation (RSVP) stream of distractors, must be detected or identified. Participants often fail to report the second of the two targets (T2) when it occurs 200–500 ms after the first (T1). Although this deficit, referred to as the attentional blink (AB; Raymond, Shapiro, & Arnell, 1992), is widely assumed to reflect a fundamental limitation in information processing (but see, e.g., Olivers, 2007, for a different view) and has been shown to be robust in a variety of task conditions, not every individual shows the effect. Recently, we reported that some individuals do not show an AB, and presented psychophysiological evidence that target processing differs between "blinkers" and "nonblinkers" (Martens, Munneke, Smid, & Johnson, 2006). Electroencephalographic (EEG) activity for both groups was recorded during execution of a task in which two visually presented letters had to be detected in a sequential stream of digit distractors. Nonblinkers showed an earlier P3 peak (induced by identified targets and associated with the updating of working memory), suggesting that they are quicker to consolidate information than blinkers. Differences in frontal brain activity were also found, such that nonblinkers showed a larger difference between target and distractor activation than blinkers. Given these results, it is an intriguing question whether nonblinkers will show a similar lack of attentional restrictions when stimuli are presented in the auditory rather than the visual modality.

Evidence for an auditory AB was first reported by Duncan, Martens, and Ward (1997). In three experiments, Duncan et al. compared cases in which both targets were auditory, both were visual, or one was visual and the other auditory. In the within-modality experiments, an AB of comparable magnitude was found. In the cross-modality experiment (i.e., when one target was visual and the other auditory), however, no AB was observed, suggesting that at least a major source of the attentional restrictions reflected in the AB must be modality-specific. Although these results have subsequently been replicated (Hein, Parr, & Duncan, 2006; Soto-Faraco & Spence, 2002), there have also been reports of cross-modality AB effects with visual and auditory target combinations (e.g., Arnell & Jenkins, 2004; Arnell & Jolicoeur, 1999; Arnell & Larson, 2002; Jolicoeur, 1999; Jolicoeur, Tombu, Oriet, & Stevanovski, 2002). Despite these mixed results, the cross-modal effect is usually found to be weaker and less stable than its within-modality counterpart (Arnell & Jenkins, 2004; Arnell & Larson, 2002; Hein et al., 2006; Potter, Chun, Banks, & Muckenhoupt, 1998; Soto-Faraco & Spence, 2002). Here, we focus on within-modality interference and test whether visual nonblinkers do or do not show an auditory AB.

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If individual differences in target processing (i.e., speed of consolidation; Martens, Munneke et al., 2006) are similar across modalities, visual nonblinkers should also be auditory nonblinkers. If, however, the limitations that underlie the visual AB are different than those that underlie the auditory AB, visual nonblinkers may well be auditory blinkers.

Experiment 1

While an AB can be observed in most people, it has been shown that some individuals, referred to as nonblinkers, 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 & Johnson, 2008; Martens, Munneke et al., 2006; Martens & Valchev, 2009). The goal of Experiment 1 was to retest individual levels of performance in a visual AB task for participants who had shown little or no AB in previous AB experiments conducted in our laboratory (e.g., Martens, Elmallah, London, & Johnson, 2006; Martens & Johnson, 2005; Martens & Valchev, 2009; Nieuwenstein, Johnson, Kanai, & Martens, 2007).

Method

Participants

A group of 14 volunteers from the University of Groningen community who were considered to be nonblinkers (aged 18–26, mean = 23.3, with normal or corrected-to-normal visual acuity) was formed. These participants were retested to ensure that the observed lack of an AB effect was consistent across experiments and testing sessions. For seven of these participants, EEG was measured as well. The EEG data and the behavioral results of these seven participants were reported in Martens, Munneke et al. (2006). AB magnitude was also measured for a group of 13 new volunteers (aged 19–29, mean = 23.3, with normal or corrected-to-normal visual acuity). All participants received payment of € 4.

Stimuli and Apparatus

The generation of stimuli and the collection of responses were controlled using E-prime 1.1 software (Schneider, Eschman, & Zuccolotto, 2002) running under Windows XP on a PC with a 2.8 GHz processor. Stimuli were digits (excluding 1 and 0) and consonants (excluding “Q” and “Y”), subtending 0.3° by 0.4° of visual angle at a viewing distance of approximately 60 cm. The stimuli were presented in black (2 cd/m^2) on a white background (88 cd/m^2) presented in 12-point Courier New font on a 17-in. cathod ray tube (CRT) monitor.

Procedure

Each participant carried out an AB task requiring the detection and identification of 0, 1, or 2 target letters presented in an RSVP stream of 16–18 distractor digits. Participants initiated each trial by pressing the space bar. A fixation cross was presented on the screen, followed 750 ms later by the stream of visual items. Each item in the stream was presented for 90 ms at the center of the screen. In two-thirds of the trials, two target letters were embedded in the stream (dual-target trials), in one-sixth of the trials only one target letter was present (single-target trials), and in one-sixth of the trials, no targets were present (no-target trials). The first target (T1) was always presented as the fifth item in the stream, and the second target (T2) was the first, second, third, or eighth item following T1. In other words, the stimulus onset asynchrony (SOA) between the targets was 90, 180, 270, or 720 ms, respectively. 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 presentation of the RSVP stream, participants identified the two presented targets, if possible, by pressing the corresponding keys on the computer keyboard. If a letter was not seen, the space bar was to be pressed instead.

The experiment consisted of three experimental blocks of 96 trials each. Before each experimental block a practice block of 24 trials was completed. A short break was allowed between the blocks. Participants completed the task in approximately 30 min.

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 the AB was at its maximum according to the following formula:

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

where SOAmin is the SOA at which T2|T1 performance of the groups is at a minimum for the task (i.e., reflecting a maximum AB), which for the visual AB task of Experiment 1 was the SOA of 270 ms.

Results and Discussion

In the visual AB task, all participants in the nonblinker group had an AB magnitude of 10% or less (range = 2.0 – 10.0%, mean = 6.8%), consistently showing the same high level of performance as in other AB experiments in which they had previously participated (averaged across experiments, AB magnitude ranged from −2.12 to 9.7%, mean = 5.4%). The 13 new volunteers showed AB magnitudes of 19.2–56.5% (mean = 39.9%), and thus all could be assigned to the blinker group.

Percentage of correct identifications in the single-target condition was 96.4% for nonblinkers and 91.8% for blinkers. In the dual-target condition, mean T1 performance was 95.2% for nonblinkers and 82.1% for blinkers. A mixed analysis of variance (ANOVA) of T1 performance with group (nonblinkers or blinkers) as a between-subjects factor and target condition (single- or dual-target) as a within-subjects factor revealed significant main effects of group,

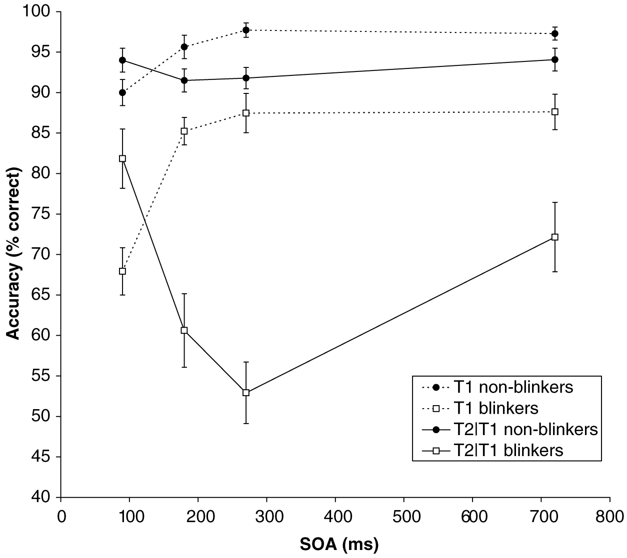

Figure 1. Mean percentage correct report of T1 and T2 given correct report of T1, as a function of stimulus onset asynchrony (SOA) between the two visual targets in Experiment 1, for nonblinkers and blinkers. Error bars reflect standard error of the mean.

$F(1, 25) = 21.87$, $MSE = 48.39$, $p < .001$, $\eta_p^2 = .47$, and target condition, $F(1, 25) = 37.22$, $MSE = 10.28$, $p < .001$, $\eta_p^2 = .61$. In addition, a significant Group × Target condition interaction was found, $F(1, 25) = 23.62$, $MSE = 10.28$, $p < .001$, $\eta_p^2 = .49$, reflecting that the dual-target condition was especially difficult for the blinkers.

Figure 1 shows the percentage correct T1 identification in dual-target trials, as well as the percentage correct T2 identification in dual-target trials given the correct report of T1, as a function of the interval between the two targets (SOA) for both groups of participants. A mixed ANOVA of T1 performance in the dual-target condition with group (nonblinkers or blinkers) as a between-subjects factor and SOA (90, 180, 270, or 720) as a within-subjects factor revealed significant effects of group, $F(1, 25) = 37.81$, $MSE = 122.44$, $p < .001$, $\eta_p^2 = .60$, and SOA, $F(3, 75) = 57.47$, $MSE = 19.86$, $p < .001$, $\eta_p^2 = .70$. In addition, a Group × SOA interaction was found, $F(3, 75) = 12.18$, $MSE = 19.86$, $p < .001$, $\eta_p^2 = .33$, suggesting that the decrement in T1 performance at Lag 1 was greater for blinkers (T1 accuracy = 67.9%) than for nonblinkers (T1 accuracy = 90.0%).

A separate mixed ANOVA of T2 performance, given correct report of T1, with group (nonblinkers or blinkers) as a between-subjects factor and SOA (90, 180, 270, or 720) as a within-subjects factor revealed significant main effects of group, $F(1, 25) = 67.79$, $MSE = 267.94$, $p < .001$, $\eta_p^2 = .73$, and SOA, $F(3, 75) = 19.16$, $MSE = 68.66$, $p < .001$, $\eta_p^2 = .43$. In addition, a significant Group × SOA interaction was found, $F(3, 75) = 13.01$, $MSE = 68.66$, $p < .001$, $\eta_p^2 = .34$, suggesting that the AB was indeed substantially larger for blinkers than for nonblinkers. Similar results were found when the unconditional T2 performance was analyzed (i.e., not conditionalized on T1 performance). A separate ANOVA of the nonblinkers' T2|T1 data showed no significant effect of SOA, $p = .16$. Given the effect size ($\eta_p^2 = .13$), an estimate of power (Clark-Carter, 1997) indicated that if we would have been able to include at least four additional nonblinkers a significant effect (at $p = .05$) might have been obtained (giving a power of .8). Therefore, we cannot conclude that there was no visual AB effect for the nonblinkers. Nevertheless, it is clear that the effect – if present – would certainly be very small, and very different in size than that of the blinkers.

Finally, we checked the intra-individual stability of performance on odd and even number trials for all participants. Spearman-Brown prophecy coefficients were .89 for T1, .97 for T2, and .90 for AB magnitude, reflecting stable within-subject performance, similar to that observed in the study by Martens and Valchev (2009).

Experiment 2

Given the clear differences in visual AB magnitude between blinkers and nonblinkers as demonstrated in Experiment 1, Experiment 2 was set up to address the question whether the same pattern of results can be found for the auditory modality. An AB task similar to that in Experiment 1 was developed using auditory rather than visual stimuli, and performed by a group of nonblinkers and blinkers.

Method

Participants

All participants from Experiment 1 volunteered to participate in Experiment 2 and received payment of € 5. The order of Experiments 1 and 2 was fixed for all participants.

Stimuli and Apparatus

Stimuli in the auditory AB task consisted of spoken letters and digits, which were digitally recorded and compressed to 120-ms duration. The stimuli were presented at approximately 83 dB using Sony MDR-V600 headphones with E-prime 1.1 software (Schneider et al., 2002) running under Windows XP on a PC with a 2.8 GHz processor.

Procedure

On each trial, a fixation cross was presented on the screen, followed 255 ms later by an auditory stimulus stream, consisting of 16–18 items. Each stimulus was presented for 120 ms, with an inter stimulus interval (ISI) of 10 ms, as a duration of 90 ms and no ISI, as in the visual AB task of Experiment 1, was shown in pilot testing to render the stimuli unintelligible. Targets were consonant letters (excluding "S", "V", and "Y"), and distractors were digits

(0, 2, 3, 4, and 8). In two-thirds of the trials, two target letters were embedded in the stream (dual-target trials), in one-sixth of the trials only one target letter was present (single-target trials), and in one-sixth of the trials, no targets were presented (no-target trials). In dual- and single-target trials, T1 was always presented as the fifth item in the stream. In dual-target trials, T2 was the first, second, third, or eighth item following T1. In other words, the SOA between the targets was 130, 260, 390, or 1040 ms, respectively. 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 presentation of the stimulus stream, the fixation cross disappeared, and participants were asked to identify the presented targets, if possible, by pressing 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. If a letter was missed, participants were instructed to press the space bar instead. Responses were accepted and counted correct in either order. After responses were collected, the next trial was automatically initiated.

The experiment consisted of three practice blocks and three experimental blocks. In the first block, all 23 stimuli were presented one by one, in isolation. Participants identified each stimulus by pressing the corresponding key on the keyboard. When all stimuli had been presented once, stimuli that were not correctly identified were presented again in random order, until all stimuli were identified correctly. The second practice block contained 16 single-target trials, during which participants were required to identify the single target letter embedded within the stream of digit distractors. Feedback was provided at the end of each trial for 1 s. The block was repeated as long as accuracy remained below 70%. On average, the block was repeated once. In the last practice block (36 trials) as well as in the experimental blocks (96 trials each), stimulus streams with either 0, 1, or 2 targets were presented, as described above. Feedback was provided in the practice blocks only. After each block, participants were allowed to take a short break. The auditory AB task lasted approximately 45 min.

Results and Discussion

In the auditory AB task, the percentage of correct identifications in the single-target condition was 83.1% for non-blinkers and 78.5% for blinkers; in the dual-target condition mean T1 performance was 82.9% for nonblinkers and 74.7% for blinkers. A mixed ANOVA of T1 performance with group (nonblinkers or blinkers) as a between-subjects factor and target condition (single- or dual-target) as a within-subjects factor revealed a significant effect of group, $F(1, 25) = 5.42$, $MSE = 102.51$, $p = .028$, $\eta_p^2 = .18$. However, neither an effect of target condition ($p = .16$) nor an interaction between group and SOA ($p = .20$) was found.

Figure 2 shows the percentage correct T1 identification in dual-target trials, as well as the percentage correct T2 identification in dual-target trials given the correct report of T1, as a function of the interval between the two targets (SOA) for both groups of participants. A mixed ANOVA of T1 performance with group (nonblinkers or blinkers) as a between-subjects factor and SOA (130, 260, 390, or 1040) as a within-subjects factor revealed significant effects of group, $F(1, 25) = 8.56$, $MSE = 213.56$, $p = .007$, $\eta_p^2 = .26$, and SOA, $F(3, 75) = 3.94$, $MSE = 33.49$, $p = .018$, $\eta_p^2 = .14$. In addition, a Group × SOA interaction was found, $F(3, 75) = 9.07$, $MSE = 33.49$, $p < .001$, $\eta_p^2 = .27$, suggesting that the decrement in T1 performance at Lag 1 was greater for blinkers (T1 accuracy = 66.9%) than for nonblinkers (T1 accuracy = 84.4%).

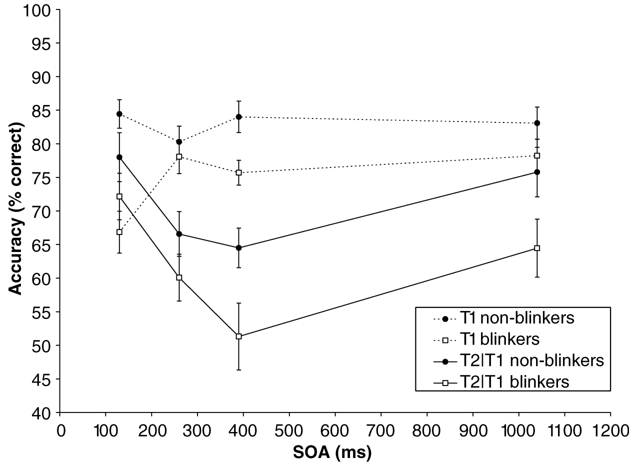

Figure 2. Mean percentage correct report of T1 and T2 given correct report of T1, as a function of stimulus onset asynchrony (SOA) between the two auditory targets in Experiment 2, for nonblinkers and blinkers. Error bars reflect standard error of the mean.

A mixed ANOVA of T2 performance, given correct report of T1, with group (nonblinkers or blinkers) as a between-subjects factor and SOA (130, 260, 390, or 1040) as a within-subjects factor revealed significant effects of group, $F(1, 25) = 4.79$, $MSE = 477.98$, $p = .038$, $\eta_p^2 = .16$, and SOA, $F(3, 75) = 16.27$, $MSE = 94.25$, $p < .001$, $\eta_p^2 = .39$. No interaction between group and SOA was found ($p = .42$). Similar results were found when the unconditional T2 performance was analyzed. As performance at the SOA of 1040 ms was still relatively low in both groups, an additional ANOVA of T2|T1 was conducted focusing on SOAs 260, 390, and 1040. Again, significant main effects were found of group, $F(1, 25) = 5.43$, $MSE = 398.34$, $p = .028$, $\eta_p^2 = .18$, and SOA, $F(2, 50) = 10.57$, $MSE = 95.64$, $p < .001$, $\eta_p^2 = .30$, and no significant Group × SOA interaction ($p = .43$).

Finally, we checked the intra-individual stability of performance on odd and even number trials. Spearman-Brown prophecy coefficients were .94 for T1, .91 for T2, and .76 for AB magnitude, reflecting stable within-subject performance, similar to that observed in Experiment 1 and in the study by Martens and Valchev (2009).

The finding of an auditory AB, as reflected in the SOA effect for T2, is in agreement with previous studies that reported an AB in the auditory modality (e.g., Duncan et al., 1997; Hein et al., 2006; Mondor, 1998; Soto-Faraco & Spence, 2002; Tremblay, Vachon, & Jones, 2005; Vachon &Tremblay, 2005, 2006). Importantly, although, overall, nonblinkers performed better than blinkers, the lack of a significant interaction between group and SOA for T2 suggests that both groups showed a similar AB. Given the small effect size of the Group × SOA interaction (η_p^2 = .03), at least four times as many participants would be required in each group for the interaction to become significant (at p = .05 and a power of .8; Clark-Carter, 1997). Assuming that about 5% of the population is a nonblinker, more than 1,000 participants would have to be tested to find the required number of nonblinkers. Therefore, we tentatively conclude that there was no substantial difference in the size of the auditory AB effect between the two groups.

Indeed, an independent sample t test showed no significant difference (p = .20) between the AB magnitude at SOA 390 (the SOA where the auditory AB was maximal) of blinkers (32.5%) and nonblinkers (23.4%). As an alternative measure of AB magnitude, the cumulative difference in T2|T1 accuracy between SOA 1040 and SOAs 260 and 390 was calculated for both groups. An independent sample t test showed no significant difference (p = .75) between blinkers (17.5%) and nonblinkers (20.5%). Even though the visual nonblinkers showed a significant auditory AB in this study, for practical reasons we will continue to refer to them as nonblinkers.

Experiment 3

In Experiment 2, a significant auditory AB effect was observed for both visual blinkers and visual nonblinkers. However, as mean T1 performance for nonblinkers was 95.2% in the visual AB task of Experiment 1 and only 82.9% in the auditory task of Experiment 2, the observed auditory AB in the nonblinker group may be due to a change in task difficulty rather than modality. In other words, the lack of an AB effect in the visual AB task may be caused by a ceiling effect. Experiment 3 was conducted to rule out this possibility.

Method

Participants

A group of eight nonblinkers (aged 20–27, mean = 23.6, with normal or corrected-to-normal visual acuity) participated in the experiment and received payment of € 4. Four volunteers had also participated in Experiments 1 and 2. The other four volunteers had also shown little or no AB in previous AB experiments in our lab. When retested with the visual AB task described in Experiment 1 they showed AB magnitudes of 2.2%, 2.5%, 3.2%, and 4.0%, respectively.

Stimuli and Apparatus

Stimuli were digits (excluding 1 and 0), consonants (excluding "Q" and "Y"), and hash signs ("#"), subtending 0.3° by 0.4° of visual angle at a viewing distance of approximately 60 cm. The stimuli were presented in black (2 cd/m^2) on a white background (88 cd/m^2) presented in 12-point Courier New font on a 17-in. CRT monitor. The apparatus was the same as in Experiment 1.

Procedure

The procedure was the same as in the visual AB task in Experiment 1 except for the following modifications. During each trial an RSVP stream was presented consisting of digit distractors and two target letters which participants were instructed to identify. Distractors were presented for 90 ms. Targets had a variable duration (with a minimum of 20 ms and a maximum of 80 ms) and were immediately followed by a masking stimulus ("#") which also had a variable duration. The total duration of a target and its mask was always 90 ms. This allowed us to vary task difficulty in order to approach the difficulty levels in the auditory AB task of Experiment 2 while keeping the SOA between the two targets the same as in the visual AB task of Experiment 1 (i.e., 90, 180, 270, or 720 ms).

Experiment 3 contained only dual-target trials. On the first trial of each block, the two targets were presented for 70 ms and their masks for 20 ms. Throughout each block of trials, mean T1 accuracy was calculated online. If the running mean T1 performance was higher than 85% on a given trial, the duration of the targets was subsequently decreased by 10 ms and, correspondingly, the duration of the masks increased by 10 ms. If mean T1 performance dropped below 75%, the duration of the targets was increased by 10 ms, and the duration of the masks decreased by 10 ms.

The experiment contained one practice block consisting of 16 trials and two experimental blocks, each consisting of 128 trials. Participants completed the task in approximately 25 min.

Results and Discussion

The mean target duration was 66 ms (SD = 6.1). Figure 3 shows the percentage correct T1 identification, as well as the percentage correct T2 identification given correct report of T1, as a function of the interval between the two targets (SOA). Separate ANOVAs of T1 and T2 (given correct report of T1) performance, with SOA (90, 180, 270, or 720) as a within-subjects factor revealed no significant effect of SOA in both cases, $F(3, 21) = 3.23$, $MSE = 18.15$, $p = .08$, $\eta_p^2 = .32$ for T1; $F(3, 21) = 3.07$, $MSE = 54.75$, $p = .08$, $\eta_p^2 = .31$ for T2|T1, reflecting only a very small (if any) AB effect. A power analysis (Clark-Carter, 1997) showed that given the effect size, the eight participants that we tested should have been sufficient to find a significant effect (at p = .05) of SOA (giving a power of .84). Spearman-Brown prophecy coefficients were .71 for T1,

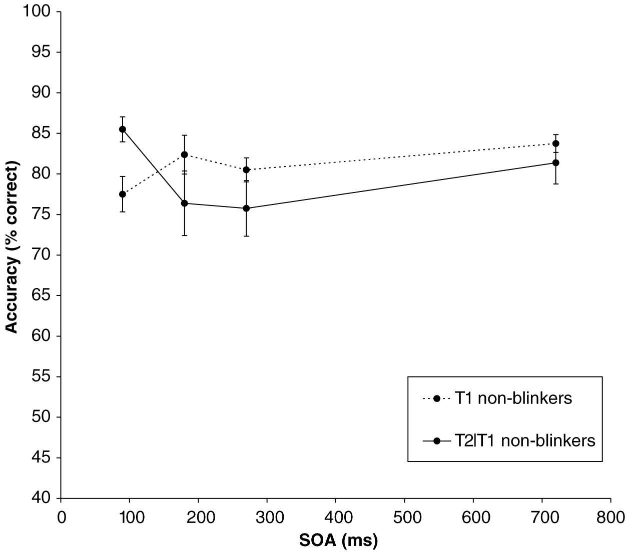

Figure 3. Mean percentage correct report of T1 and T2 given correct report of T1, as a function of stimulus onset asynchrony (SOA) between the two visual targets in Experiment 3, for nonblinkers. Error bars reflect standard error of the mean.

.82 for T2, and .91 for AB magnitude, reflecting stable intra-individual performance, similar to that observed in Experiment 1 and in the study by Martens and Valchev (2009).

As can be seen in Table 1, mean T1 performance of the nonblinkers (81.0%) was comparable to the nonblinkers' T1 performance in the auditory task (82.9%), as well as the blinkers' T1 performance in the visual task of Experiment 1 (82.1%). This reflects equivalent task difficulty. However, while AB magnitude in the auditory task was 23.4%, the nonblinkers' AB magnitude in Experiment 3 remained well below 10%. The results strongly suggest that the nonblinkers' AB effect in the auditory task of Experiment 2 is attributable to the stimulus modality rather than the difficulty of the task, and that the nonblinkers' lack of a strong AB effect in the visual task of Experiment 1 was not due to ceiling effects.

General Discussion

The aim of this present study was to address the question whether individuals who show little or no visual AB also tend to show no temporal restrictions within the auditory modality. Auditory letter identification performance of these visual nonblinkers was compared to the auditory performance of individuals who show a substantial visual AB (blinkers). A clear auditory AB effect was observed for both blinkers and nonblinkers under conditions that were comparable to the conditions in which a lack of a visual AB was consistently found for the nonblinkers.

Some researchers have previously argued that the AB is caused by a central, a-modal bottleneck (e.g., Arnell & Jolicoeur, 1999; Arnell & Larson, 2002). However, our finding that a group of individuals can show attentional restrictions within the auditory modality but not within the visual modality suggests that the restrictions reflected by the AB are at least partly modality-specific. This is in line with previous AB studies in which it was suggested that a major source of attentional restrictions must lie in modality-specific sensory systems (Duncan et al., 1997; Hein et al., 2006; Potter et al., 1998; Soto-Faraco & Spence, 2002). The interference observed in within-modality AB paradigms may reflect both within- and cross-modality limitations, whereas cross-modality AB paradigms reflect only central limitations, thus explaining why the AB is often found to be smaller across modalities.

The current results also suggest that consolidation speed alone is unlikely to be the major factor in determining whether or not a blink is likely to occur. Martens, Munneke et al. (2006) suggested that, compared to blinkers, nonblinkers may consolidate information more quickly because nonblinkers are better in selecting target information at an early stage, thus rejecting distractors more easily and leaving sufficient resources available to report both targets. Martens and Valchev (2009) showed that indeed, nonblinkers are better in ignoring distractors than blinkers. Apparently, under the current experimental conditions, this early selection of relevant targets and the efficient rejection of irrelevant distractors is possible for nonblinkers when information is presented within the visual modality, but not when it is presented within the auditory modality.

One may argue that nonblinkers do not show a visual AB in this study – or in previous ones – due to performance being at ceiling. An auditory AB effect might thus be observable for nonblinkers because T1 performance was much lower in this task (82.9%), as compared to T1 performance in the visual AB task (95.2%). In other words, nonblinkers may have shown an auditory AB because the auditory task was more difficult than the visual task. Experiment 3 ruled out this possibility by showing that even when identification difficulty was manipulated to equate T1 performance in the visual AB

Table 1. Mean percentage correct report of T1 and AB magnitudes for blinkers and nonblinkers for each task

	Blinkers		Nonblinkers	
	T1	AB	T1	AB
Visual (Experiment 1)	82.1 (1.90)	39.9 (3.46)	95.2 (1.05)	6.1 (0.96)
Auditory (Experiment 2)	74.7 (2.17)	32.5 (6.14)	82.9 (1.82)	23.4 (2.62)
Visual control (Experiment 3)			81.0 (1.33)	5.9 (3.93)

Note. Standard error of the mean is given in parentheses.

task with that in the auditory AB task, nonblinkers continued to show little or no AB effect.

Additional evidence that ceiling effects cannot explain the pattern of data reported here is provided in Martens, Munneke et al.'s (2006) Experiment 2, in which T1 difficulty was varied by systematically shortening the duration of each RSVP item. For a given level of T1 performance (thus equating task difficulty across groups), blinkers and nonblinkers showed large differences in AB magnitude, with the latter group continuing to show little or no visual AB. Therefore, we conclude that (a) the lack of a visual AB effect observed in nonblinkers is not due to a ceiling effect and (b) that the change of modality – rather than the change in task difficulty – is most likely responsible for the observation that visual nonblinkers show an auditory AB.

Conclusions

Taken together, we show that nonblinkers, who evidence little or no AB when required to identify two visually presented letters amidst a stream of digit distractors, do show an AB under comparable experimental conditions with auditory stimuli. Clearly, more research is needed to address the question of whether there are structural differences between nonblinkers and blinkers that will also be reflected in other cognitive tasks (see e.g., Arnell, Howe, Joanisse, & Klein, 2006; Colzato, Spapè, Pannebakker, & Hommel, 2007; Martens & Johnson, 2008), or whether the differential performance is due to the way nonblinkers approach one quite specific RSVP task. In either case, studying individual differences in attentional selection seems to be a promising approach to understanding attentional limitations.

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References

Arnell, K. M., Howe, A. E., Joanisse, M. F., & Klein, R. M. (2006). Relationships between attentional blink magnitude, RSVP target accuracy, and performance on other cognitive tasks. *Memory & Cognition, 34*, 1472–1483.

Arnell, K. M., & Jenkins, R. (2004). Revisiting within-modality and cross-modality attentional blinks: Effects of target-distractor similarity. *Perception & Psychophysics, 66*, 1147–1161.

Arnell, K. M., & Jolicoeur, P. (1999). The attentional blink across stimulus modalities: Evidence for central processing limitations. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 630–648.

Arnell, K. M., & Larson, J. M. (2002). Cross-modality attentional blinks without preparatory task-set switching. *Psychonomic Bulletin & Review, 9*, 497–506.

Clark-Carter, D. (1997). *Doing quantitative psychological research: From design to report*. Hove, UK: Psychology Press.

Colzato, L. S., Spapè, M., Pannebakker, M., & Hommel, B. (2007). Working memory and the attentional blink: Blink size is predicted by individual differences in operation span. *Psychonomic Bulletin & Review, 14*, 1051–1057.

Duncan, J., Martens, S., & Ward, R. (1997). Restricted attentional capacity within but not between sensory modalities. *Nature, 387*, 808–810.

Hein, G., Parr, A., & Duncan, J. (2006). Within-modality and cross-modality attentional blinks in a simple discrimination task. *Perception & Psychophysics, 68*, 54–61.

Johnson, A., & Proctor, R. W. (2004). *Attention: Theory and Practice*. CA: Sage Publications.

Jolicoeur, P. (1999). Restricted attentional capacity between sensory modalities. *Psychonomic Bulletin & Review, 6*, 87–92.

Jolicoeur, P., Tombu, M., Oriet, C., & Stevanovski, B. (2002). From perception to action: Making the connection. In W. Prinz, & B. Hommel (Eds.), *Attention and perfromance, XIX* (pp. 558–586). Oxford, UK: Oxford University Press.

Martens, S., Elmallah, K., London, R., & Johnson, A. (2006). Cuing and stimulus 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 and Cognition, 33*, 234–240.

Martens, S., & Johnson, A. (2008). Working memory capacity, intelligence, and the magnitude of the attentional blink revisited. *Experimental Brain Research.* doi: 10.1007/s00221-008-1551-1.

Martens, S., Munneke, J., Smid, H., & Johnson, A. (2006). Quick minds don't blink: Electrophysiological correlates of individual differences in attentional selection. *Journal of Cognitive Neuroscience, 18*, 1423–1438.

Martens, S., & Valchev, N. (2009). Individual differences in the attentional blink: The important role of irrelevant information. *Experimental Psychology, 56*, 18–26.

Mondor, T. A. (1998). A transient processing deficit following selection of an auditory target. *Psychonomic Bulletin and Review, 5*, 305–311.

Nieuwenstein, M. R., Johnson, A., Kanai, R., & Martens, S. (2007). Cross-task repetition amnesia: Impaired recall of RSVP targets held in memory for a secondary task. *Acta Psychologica, 125*, 319–333.

Olivers, C. N. L. (2007). The time course of attention: It's better than we thought. *Current Directions in Psychological Science, 16*, 11–15.

Potter, M. C., Chun, M. M., Banks, B. S., & Muckenhoupt, M. (1998). Two attentional deficits in serial target search: The visual attentional blink and an amodal task-switch deficit. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 979–992.

Raymond, J. E., Shapiro, K. L., & Arnell, J. E. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18*, 849-860.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002), *E-Prime user's guide*. Pittsburgh: Psychology Software Tools.

Soto-Faraco, S., & Spence, C. (2002). Modality specific auditory and visual temporal processing deficits. *Quarterly Journal of Experimental Psychology, 55A*, 23–40.

Tremblay, S., Vachon, F., & Jones, D. M. (2005). Attentional and perceptual sources of the auditory attentional blink. *Perception & Psychophysics, 67*, 195–208.

Vachon, F., & Tremblay, S. (2005). Auditory attentional blink: Masking the second target is necessary, delayed masking is

sufficient. *Canadian Journal of Experimental Psychology, 59*, 279–286.
Vachon, F., & Tremblay, S. (2006). Delayed masking and the auditory attentional blink: A test for retrieval competition and bottleneck models. *Experimental Psychology, 53*, 182–190.

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