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RESEARCH ARTICLE

Endogenous orienting is reduced during the attentional blink

Feng Du · Richard A. Abrams

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Abstract We studied endogenous cuing during the attentional blink in order to examine its resistance to dual task interference. In two experiments, we found a reduced impact of endogenous cuing during the “blink” time of the attentional blink. In a third experiment endogenous cuing was intact when it was not influenced by demands imposed by an earlier target. Contrary to a recent report (Zhang et al. in Exp Brain Res, 185, 287–295, 2008), the results indicate that endogenous orienting guided by semantic cues is susceptible to the attentional blink.

Keywords Attentional blink · Endogenous orienting · Reflexive orienting

Introduction

Recently, covert orienting of attention under dual task situations has been intensively studied in order to examine its resistance to perceptual interference. Presumably, reflexive orienting, also known as exogenous orienting, should remain intact even while performing a secondary task because such orienting is believed to be automatic (Jonides 1981; Posner 1980; Yantis and Jonides 1984). However, several recent studies have challenged that traditional belief by showing that reflexive orienting induced by abrupt onsets is susceptible to a concurrent monitoring task. For example, Boot and colleagues found that abrupt onsets failed to capture attention in visual search when subjects had to perform a concurrent auditory 1- back task (Boot et al. 2005). Another recent study showed that both reflexive visual and auditory orienting were disrupted when subjects were instructed to attend to a RSVP or RSAP stream (Santangelo et al. 2007).

The attentional blink (AB) refers to people’s inability to detect or identify a second target (designated T2) that follows within a few hundred milliseconds of an earlier target (T1) in the same location (Raymond et al. 1992). The AB paradigm has been used to more deeply explore the attentional demands of the processing of various stimuli. For example, in a pioneering study Joseph et al. (1997) showed that even detection of an orientation singleton may be impaired during the attentional blink. Following this line, a recent study showed that exogenous cuing by uninformative abrupt onsets is also suppressed shortly after a target is identified in the AB paradigm (Du and Abrams 2009). Du and Abrams presented an uninformative exogenous cue shortly after T1, yet always 100 ms prior to the second target (T2) in their study. They found that the benefit of the exogenous cue was reduced if the cue was presented within 100–200 ms after T1, when the attentional blink would be strongest, but it recovered as the interval between T1 and the cue increased. Thus, the exogenous cuing effect was reduced by the attentional blink.

Each of the aforementioned studies leads to the conclusion that reflexive orienting is susceptible to a concurrent attentional load. This challenges the traditional idea that reflexive orienting is automatic. In contrast to the situation with reflexive orienting, researchers have generally believed that *endogenous* orienting is under a person’s voluntary control and does demand attentional resources. Naturally, if endogenous orienting is truly attention demanding, we would predict that the attentional blink would interrupt endogneous cuing as it does reflexive cuing.

F. Du (✉) · R. A. Abrams
Department of Psychology, Washington University,
St. Louis, MO 63130, USA
e-mail: fdu@artsci.WUSTL.edu

Surprisingly, a recent study suggests that endogenous cuing may remain intact during the attentional blink (Zhang et al. 2008). In the experiment, four boxes appeared in the display: above, below, to the left and to the right of a central fixation cross. Participants had to first identify a single target letter (T1) in the box above or below fixation which was followed by a predictive central arrow pointing to one of the boxes to the left or right. Another target letter (T2) appeared in the left or right box either 360 or 720 ms after the first target. Zhang et al. found that T2 identification was better when T2 was validly cued than when it was invalidly cued or uncued. More importantly, the magnitude of cuing at the 360 ms delay, when the attentional blink might have been strong, was the same as that at the 720 ms delay, when the attentional blink would have been weak or nonexistent. Therefore, Zhang et al. concluded that "the AB did not affect the processes involved in the endogenous control of spatial selective attention." The finding that endogenous orienting is resistant to dual task interference has potentially important implications, but appears to be at odds with the findings showing that even exogenous orienting is not immune to the effects of the attentional blink (e.g., Du and Abrams 2009).

However, several features of the Zhang et al. (2008) study may have caused them to overestimate the strength of endogenous cuing. First, the shortest T1–T2 interval in their study was 360 ms—which may be longer than the most severely impaired period of the AB. Thus, endogenous cuing might be reduced at T1–T2 intervals shorter than 360 ms. Secondly, the T2 in the Zhang et al. study always appeared abruptly as the sole new object in the display. Some recent studies, however, have shown a synergistic effect between onset capture and contingent capture. In those studies attentional capture effects were enhanced when an onset stimulus also matched the sought-for feature (Du and Abrams 2008, 2010; Ludwig and Gilchrist 2003). Thus endogenous cuing in the Zhang et al. study might be complicated by onsets of T2. Finally, the T1-cue interval covaried with cue-T2 interval in the earlier study because the researchers inserted central cues in between T1 and T2. The amount by which the T1-cue interval decreased was exactly equal to the increment in the cue-T2 interval. This is a potential problem because these two changes might be expected to produce offsetting effects: As the T1-cue interval decreases, T1 may become more likely to suppress the endogenous cue. However, the corresponding increment in the cue-T2 interval might be expected to facilitate the endogenous cuing effect. Thus it is difficult to delineate the individual effects of the T1-cue interval and the cue-T2 interval in the prior study.

The current study was designed to examine whether endogenous orienting is truly immune to the AB. In order to study that, we made a few important methodological changes over the study by Zhang et al. (2008). First, we examined the time course of endogenous cuing more thoroughly: from 100 to 700 ms in Experiment 1 and from 100 to 500 ms in Experiment 2. These time ranges include the interval during which the AB should be strongest. Secondly, T2 in our experiments was always accompanied by a distractor presented simultaneously on the opposite side of the display. Thus T2 was not the sole new object, and its unique onset would not complicate the interpretation of the effect of the endogenous cues. Thirdly, we used T1 (the letter L or R) as a spatial cue. By doing so, the T1–T2 interval is the same as the cue-T2 interval and the T1-cue interval is kept at zero in Experiment 1. Thus the effect of cue-T2 interval can be separated from the effect of T1-cue interval. Finally, it is believed that participants need some time to interpret endogenous cues before they can reorient their attention. Therefore, we presented the spatial cues in Experiment 2 far in advance of the second target in order to separate the interpretation of the cue from the movement of attention.

Experiment 1

The present experiment was designed to examine whether endogenous orienting is truly immune to the attentional blink. Unlike the Zhang et al. study in which only 360 and 720 ms T1–T2 intervals were examined, we measured the endogenous cuing effect more thoroughly from 100 to 700 ms in the present experiment. In addition, two other methodological steps were taken to ensure that a purely endogenous cuing effect was produced in the present experiment. First, the appearance of the second target (T2) was always accompanied by a distracting symbol "#" that appeared on the opposite side of the display. This ruled out the possibility that the onset of T2 would enhance the endogenous cuing effect—a possibility in the Zhang et al. (2008) study. Second, the spatial cue was a letter (L or R), instead of an arrow as used by Zhang et al. (2008), because arrows have been shown under some conditions to act like exogenous cues (Hommel et al. 2001), and hence they might not induce a purely voluntary orienting.

Method

Participants

Twenty-two undergraduates from Washington University each participated in a 45 min session for course credit. All had normal or corrected-to-normal visual acuity.

Apparatus and procedure

Stimuli were presented on a CRT in a dimly lit room at a viewing distance of 56 cm. The sequence of events on a trial is illustrated in Fig. 1. Three horizontally aligned boxes were presented as placeholders. Each box was 2.2° in width and 2.2° in height. The middle box was at the center of the screen. There was a 7.1° gap between neighboring boxes. Each trial began with a 1000 ms presentation of a gray fixation cross in the middle box, followed by the sequential presentation of multiple upper case gray letters in the same box. The letters were selected randomly without replacement from the English alphabet, excluding "I". Letters were 1.0° in width and 1.3° in height. Each letter was presented for 50 ms, followed by a 50 ms presentation of the empty placeholder boxes. The participants were required to discriminate the letter L or R in the sequence as T1. Across trials, the target letter appeared in the 10th through 12th frame of the letter sequence. After a variable number of frames (0, 1, 2, 3, 4, or 6) of distractors in the middle box, T2 appeared as a sole gray probe letter in either the left or right boxes, accompanied by a gray pound sign (#) on the opposite side. Therefore T2 could either appear at lags of 1, 2, 3, 4, 5, or 7 after the onset of T1 (100, 200, 300, 400, 500 or 700 ms, respectively) with equal probability. T2 could be any letter except L or R. Each trial ended with presentation of "#" in each of the three boxes.

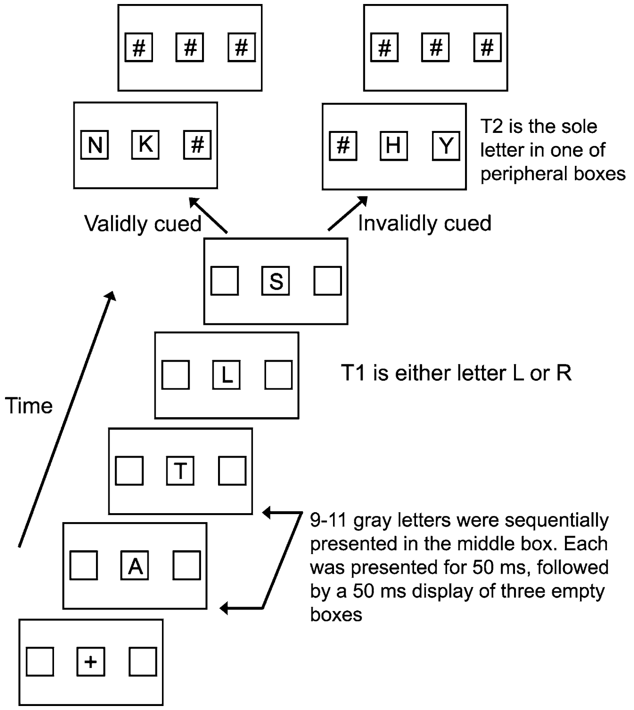

Fig. 1 A schematic illustration of the sequence of events in Experiment 1

In the current experiment, T1 (either *L* or *R*) also acted as an endogenous cue which predicted T2's location for two-thirds of the trials. An *L* indicated that T2 was most likely to appear in the left box; an *R* predicted the right box. Participants were explicitly told to use this information. The trials on which T2 appeared in the box predicted by T1 were *validly cued* trials. The other one-third of the trials were *invalidly cued* trials. Participants reported the identities of T1 and T2 by pressing keys after each trial, with equal emphasis placed on both tasks.

Design

Each trial used one of six inter-target lags (Lag 1, Lag 2, Lag 3, Lag 4, Lag 5 or Lag 7) and two cue-validity conditions (validly cued and invalidly cued). There were a total of 120 *invalidly cued* trials, 20 replications of each inter-target lag. There were 240 *validly cued* trials altogether and each inter-target lag included 40 replications. All 360 trials were presented in a random order. Participants were apprised of the fact that the first target (T1) indicated the T2 location with 70% probability (the cue validity was exaggerated slightly in order to encourage the use of the cue). Participants first served in one block of 24 trials for practice. They received a brief break after every 90 test trials.

Results

The average accuracy of T1 identification collapsed across all lags and cue validities was 0.95. Accuracy data for T1 were submitted to an ANOVA, which revealed a main effect of cue validity, $F(1,21) = 9.22$, $P < 0.01$, $\eta_p^2 = 0.305$; with higher accuracy on validly cued trials (0.96) than on invalidly cued trials (0.94). There was no main effect of lag, nor was there an interaction.

The accuracy of identification of T2 is plotted in Fig. 2 as a function of the cue validity and inter-target lag. First, there was a significant main effect of cue validity, with higher accuracy when the cue was valid relative to when it was invalid, $F(1,21) = 11.02$, $P = 0.003$, $\eta_p^2 = 0.344$. Most importantly, the interaction between lag and cue validity was significant, $F(5,105) = 8.78$, $P < 0.001$, $\eta_p^2 = 0.295$. Further paired sample t tests revealed no cuing effect at either Lag1 ($t(21) = 0.31$, $P = 0.762$) or Lag 2 ($t(21) = 1.39$, $P = 0.180$) but a significant cuing effect at Lags 3 to 7 ($t(21) = 2.68$, $P = 0.014$; $t(21) = 2.27$, $P = 0.034$; $t(21) = 3.86$, $P = 0.001$; $t(21) = 4.09$, $P = 0.001$; for Lag 3, 4, 5 and 7, respectively). Thus, the endogenous cueing effect was absent at short lags, during the attentional blink, but was evident at longer lags.

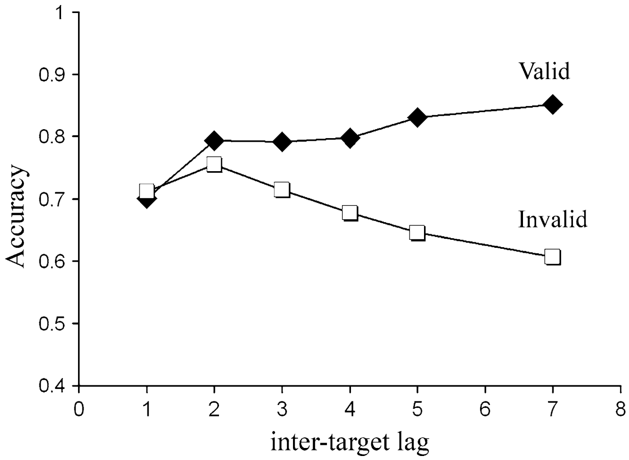

Fig. 2 Accuracy of T2 identification in Experiment 1, given correct identification of T1

We found no main effect of inter-target lag, $F(5,105) = 1.45$, $P = 0.213$, $\eta_p^2 = 0.065$, despite the significant interaction between effects of lag and cue validity. This raises a question regarding the extent to which our paradigm is even capable of producing AB. If it was we might expect an overall increase in T2 accuracy with increasing inter-target lag. Indeed, such a pattern was observed following valid cues, but after an invalid cue T2 accuracy actually decreased with increasing lag. We believe that AB was generated in both conditions, but its presence in the invalid condition was masked by our presentation of an endogenous cue on every trial. Nevertheless, our conclusions would be strengthened if we could verify that our method is indeed capable of producing an AB when there is no endogenous cue. To that end, we conducted a control experiment with 15 subjects. In the control experiment, all of the stimuli and procedural details were the same as those in Experiment 1, except that participants were never told that the first target (either *L* or *R*) is predictive for the T2 location (thus there was no endogenous cue; inter-target lag was the only independent variable). If the AB occurs in this no-cue version of Experiment 1, a similar AB can be presumed to have been present but masked in the invalid condition of Experiment 1. In the control experiment, the conditional accuracy of T2 identification given T1 was correctly reported indeed increased with increasing lag [0.69 for lag 1, 0.76 for lag 2, 0.79 for lag 3, 0.82 for lag 4, 0.81 for lag 5, and 0.82 for lag 7]. A one-way ANOVA by inter-target lag indicates that the AB is indeed generated by our procedure $F(5,70) = 5.577$, $P < .001$, $\eta_p^2 = 0.285$.

Discussion

In the present experiment an endogenous cue provided no benefit when the lag between the first and second target was brief, during the time at which the attentional blink would be most severe. But a cuing effect did emerge at longer inter-target intervals, when the attentional blink would be expected to be weak or nonexistent. The results suggest that endogenous orienting driven by a semantic cue is sensitive to the available attentional resources. The finding is consistent with traditional beliefs about the nature of endogenous cuing effects, but inconsistent with recent results reported by Zhang et al. (2008).

In the present experiment, the endogenous cue was time-locked to T1 (indeed, it was T1). As a result, the interval between T1 and T2 was identical to the interval between the cue and T2, and thus the time available to process the information in the cue increased as the inter-target lag increased. Because the short lags are precisely the conditions under which the cue was not useful, it is possible that participants simply did not have enough time to interpret the cue at short lags. That could account for the absence of a cuing effect at short lags, instead of the explanation that we offered. Experiment 2 addressed that concern.

Experiment 2

Previous studies have shown that endogenous cues such as central arrows yield facilitation approximately 100 ms after their onset, presumably reflecting the time needed to process the cue (Müller and Rabbitt 1989). Cues such as the L or R used in Experiment 1 might require even more time to be fully decoded. Therefore, the absence of endogenous cuing for the first 200 ms following T1 in Experiment 1 might be attributable to the time needed to process the letter cues. To rule out this possibility, in the present experiment we presented the cues (the word *left* or *right*) at the beginning of each trial, far in advance of T2. This change in procedure guarantees that participants had sufficient time to process the endogenous cues and to plan their orienting even before T1 appeared. If endogenous orienting is immune to the AB, the cuing effect should be evident across all inter-target lags. The present experiment tested that possibility.

Method

Participants

Twenty undergraduates of Washington University each participated in a 30 min session for course credit. All had normal or corrected-to-normal visual acuity.

Apparatus and procedure

The stimuli and procedure were similar to those in Experiment 1, with a few important changes. In particular, each trial began with a 1500-ms presentation of a cue word (either *left* or *right*) indicating the location of T2 with 67% validity. The cue was followed by an RSVP stream of gray letters as in Experiment 1, but here T1 was light gray (slightly brighter than the other letters) and no longer predictive of T2's location. T1 was a letter randomly chosen from the English alphabet, excluding "I". The second target (T2) was a letter other than the letter of T1. T2 appeared (in the left or right box) 0, 1, 2, or 4 frames after T1 (lags 1, 2, 3, or 5, respectively). Participants reported the identities of T1 and T2 by pressing keys after each trial, with equal emphasis on both tasks.

Design

Each trial used one of four inter-target lags (0, 1, 2, or 4 letters) and two cue-validity conditions (validly cued and invalidly cued). There were a total of 64 invalidly cued trials, 16 replications of each inter-target lag. There were 128 validly cued trials altogether and each inter-target lag included 32 replications. All 192 trials were mixed together and presented in a random order. Participants were told that cue words indicated the probe location with 70% probability (the cue validity was exaggerated slightly in order to encourage the use of the cues). Subjects first served in one block of 16 trials for practice. They received a brief break after every 64 test trials.

Results

The average accuracy of T1 identification collapsed across all lags and cue validity was 0.92. Accuracy data for T1 were submitted to an ANOVA which revealed no main effects or interaction (all $P > 0.5$). Thus, as would be expected, the endogenous cues had no influence on identification of T1.

The accuracy of T2 is plotted in Fig. 3 as a function of the cue validity and inter-target lag. First, there was a significant main effect of cue validity, with higher accuracy when the cue was valid relative to when the cue was invalid, $F(1,19) = 9.28, P = 0.007, \eta_p^2 = 0.328$; The main effect of inter-target lag was also significant, $F(3,57) = 4.49, P = 0.007, \eta_p^2 = 0.191$; with higher accuracy at longer lags, revealing the presence of an overall AB effect. And most importantly, the interaction between lag and cue validity was significant, $F(3,57) = 7.52, P < 0.001, \eta_p^2 = 0.284$. Paired sample t tests revealed no cuing effect at either Lag1 ($t(19) = 0.211, P = 0.835$) or Lag 2 ($t(19) = 1.19, P = 0.247$) but a significant cuing effect at Lag 3 and Lag 5 ($t(19) = 2.39, P = 0.028$; $t(19) = 4.39, P < 0.001$; respectively for Lags 3 and 5). This pattern of results replicates the results of Experiment 1 and indicates that an endogenous cueing effect was absent at short lags but was present at longer lags.

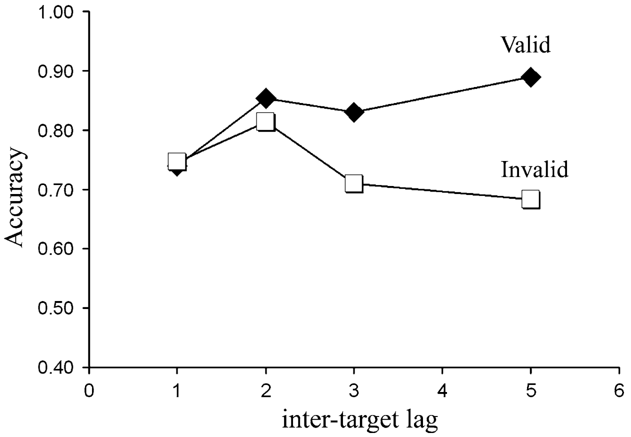

Fig. 3 Accuracy of T2 identification in Experiment 2, given correct identification of T1

Discussion

In the present experiment, subjects were provided with an endogenous cue far in advance of the RSVP stream that contained the two targets. They had only to identify the first target and then orient their attention to the previously cued location to identify the second target[1]. Despite the advance presentation of the cue, subjects were unable to benefit from the cued information within 200 ms after T1. Thus, people appear unable to execute a planned endogenous movement of attention during the "blink" time of the AB, replicating the results of Experiment 1.

Experiment 3

In Experiment 2, participants had sufficient time to process the cue words and to plan the orienting of attention in advance. But the absence of an endogenous cuing effect during the AB indicates that even a planned movement of attention is delayed or suppressed by AB. However,

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[1] The endogenous cue (the word *left* or *right*) in Experiment 2 was presented at the beginning of each trial, far in advance of T1 and T2. As an anonymous reviewer suggested, in theory, participants could move their attention to the cued location in the periphery prior to presentation of T1. Thus the disruption caused by the AB at short lags might have been due to processes other than those involved in moving attention. However, if subjects had moved their attention to the cued location in the periphery early in the trial, then we would also expect to have observed very low accuracy in T1 identification. Contrary to that prediction, T1 accuracy was quite high (92%), consistent with our belief that the AB interfered with the movement of attention after T1 was presented.

whether this suppression upon endogenous cuing was truly caused by processing T1 remains unanswered. To address this question, it is necessary to examine whether cue words presented at the beginning of each trial can produce a cuing effect when participants do not need to identify T1 (thus no occurrence of AB). By measuring the endogenous cuing effect under this single task situation, we can establish a baseline for endogenous cuing without concurrent interference from AB.

Method

Participants

Nineteen undergraduates of Washington University each participated in a 30 min long session for course credit. All had normal or corrected-to-normal visual acuity.

Apparatus, procedure and design

The stimuli and procedure were very similar to those of Experiment 2 except for one change. In the present experiment, participants were required to report only the identity of T2 (a random letter in one peripheral box). T1 (a light gray letter) was presented in the RSVP stream as it had been in Experiment 2, but subjects were not required to report it.

Results and discussion

The accuracy of T2 is plotted in Fig. 4 as a function of the cue validity and inter-target lag. A two-way ANOVA revealed a significant main effect of cue validity, with higher accuracy when the cue was valid relative to when it was invalid, $F(1,18) = 4.62$, $P = 0.045$, $\eta_p^2 = 0.204$. No main effect of inter-target lag or interaction was found (all $F < 1$). This pattern of results indicates that a cue word presented at the beginning of each trial can produce an endogenous cuing effect consistently across all inter-target lags.

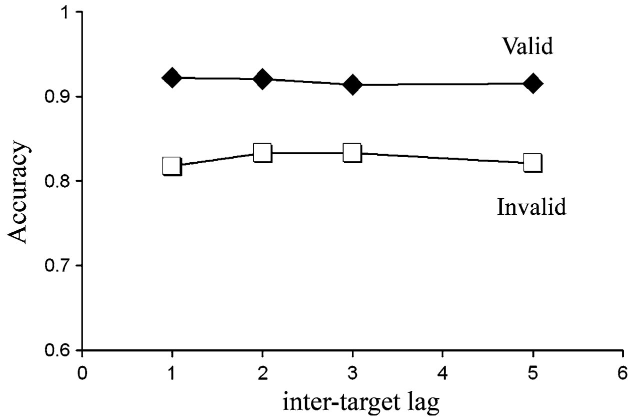

Fig. 4 Accuracy of T2 identification in Experiment 3

General discussion

Experiment 1 showed that the endogenous cuing effect induced by T1, the first of two successive targets, was suppressed during the attentional blink. In Experiment 2 participants were provided the spatial cues far in advance, yet they still could not carry out the endogenous movement of attention during the AB. Because voluntary orienting guided by a predictive cue was susceptible to the attentional impairment caused by the AB, we conclude that such orienting is not truly automatic, consistent with commonly held views of endogenous cuing (but inconsistent with the conclusions of Zhang et al. 2008).

In addition, Experiment 3 showed that endogenous cuing produced by the same cues used earlier remained constant across all inter-target lag when participants were only required to report T2 (i.e., in the absence of an attentional blink). Thus, the impairment in the first two experiments can be more confidently attributed to the AB. Experiment 3 additionally provides a baseline estimate of endogenous cuing effects under single task conditions: a 9% cuing effect was observed there. In contrast, in Experiment 2 the endogenous cuing effects were 12% at lag 3 and 21% at lag 5, which was much higher than that in Experiment 3. A closer look at Figs. 2 and 3 reveals that participants seemed to improve their accuracy on validly cued trials at the cost of that on invalidly cued trials.

Our conclusions are consistent with widely held beliefs about the attentional demands of endogenous cues, but they differ from those of Zhang et al. (2008). The most obvious reason lies in the difference in the time course of the stimulus events in the two studies. We showed the absence of endogenous cuing within the first 200 ms of AB[2], but cuing effects were clearly present 300–500 ms after T1 onset in both Experiment 1 and Experiment 2. Thus it is not surprising that Zhang et al. (2008) observed an intact cuing effect at 360 ms, their shortest T1–T2 interval.

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[2] Although endogenous orienting was suppressed for 200 ms in both Experiments 1 and 2, we think the duration of the suppression might depend on the difficulty of T1 discrimination. In an earlier study on exogenous orienting we found that suppression caused by the processing of T1 extended longer when the T1 task was more demanding (Du and Abrams 2009). Further studies on the time course of suppression of endogenous orienting are needed.

Any influence of the AB upon cueing might have been long gone at their shortest lag.

There is also another difference between our experiments and that of Zhang at el. (2008) that might also account for the discrepant conclusions. In the Zhang et al. (2008) study, the target to be identified was a single letter that appeared abruptly in a peripheral box. The abrupt onset of the target in that case might have provided stimulus-driven guidance of attention. On the other hand, we asked subjects to search for a single peripheral letter which was accompanied by a distracting "#" on the other side of the screen. This change made it impossible for participants to use the onset of T2 to summon their spatial attention. The viability of this alternative explanation is supported by earlier findings which showed that a combination of onset capture and top-down guidance can produce cuing that remains intact during the AB (Ghorashi et al. 2007).

Before concluding, it is worth considering the possibility that the suppressed voluntary orienting that we observed during the first 200 ms of the AB might have arisen as a result of a sort of "task switching" cost. In particular, it might be argued that our task required subjects to first move attention from the center to a peripheral location prior to identifying T2, and that this attention movement demanded some resources for a brief period of time—impairing identification of T2. We think it is unlikely that such attention movements could explain our findings. In particular, there is a large body of work on both endogenous and exogenous orienting that suggests that any cost associated with movements of attention are very quickly (100 ms or less) offset by the benefit of having moved attention to the target location. Second, a recent study by Ghorashi et al. (2007) examined perceptual discriminations preceded by attention shifts and they found no impairment associated with the attention shift. Thus we think the present results reflect an impairment caused by the demands of processing T1.

Several studies have shown that onset capture without the aid of top-down guidance of attention is interrupted by adding a secondary task (Boot et al. 2005; Du and Abrams 2009; Santangelo et al. 2007). These findings along with the current study indicate that neither exogenous nor endogenous cuing is immune to the attentional blink. However, a combined effect of both endogenous guidance (by central cues) and exogenous capture (by onsets) provides a much stronger resistance to interference (Ghorashi et al. 2007; Zhang et al. 2008). Such a result is also consistent with previous studies showing that a synergistic effect between bottom-up salience and top-down guidance is actually stronger than the individual effects of either bottom-up salience or top-down guidance in isolation (Du and Abrams 2008; Ludwig and Gilchrist 2003). But when the purely endogenous cuing effects are considered, it is clear that they require attentional resources, consistent with most theoretical conceptions.

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