

Onset capture requires attention

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We studied exogenous cuing caused by an uninformative abrupt onset during a time when subjects were under the influence of the attentional blink. In two experiments, we found a reduced impact of exogenous cuing during the blink time of the attentional blink. The results indicate that involuntary orienting caused by abrupt onsets is sensitive to manipulation of available attentional resources. Thus, onset capture requires attention.

Reflexive orienting, also known as *exogenous orienting*, has been distinguished from voluntary orienting for decades (e.g., Jonides, 1981; Posner, 1980). It is believed that *voluntary orienting* is under a person's volitional control and is attention demanding, whereas *reflexive orienting* is effortless and involuntary. This distinction can be seen when an event such as an abrupt onset summons a person's attention in the absence of voluntary control (Christ & Abrams, 2006; Jonides, 1981; Yantis & Jonides, 1984). In addition, a very rapid search rate for onset targets relative to nononset targets is consistent with the idea that onset capture is highly automatic or load insensitive (Yantis & Jonides, 1984; Yantis & Hillstrom, 1994).

The insensitivity of onset capture to a concurrent perceptual or attentional load was corroborated by a recent study on the attentional blink (AB). The attentional blink refers to an impairment in the detection or identification of a second target that follows within about 500 msec of an earlier target in the same location (Raymond, Shapiro, & Arnell, 1992). The impairment, or blink, lasts for a few hundred milliseconds. If onset capture is truly not attention demanding, abrupt onsets in the periphery should capture attention even if they occur during the blink time of the AB. Consistent with this prediction, Ghorashi, Di Lollo, and Klein (2007) reported an intact cuing effect elicited by abrupt onsets during the AB (see Joseph, Chun, & Nakayama, 1997, for an experiment with a similar approach). In Ghorashi et al.'s study, after the appearance of the first target in a central RSVP stream, a solid square was presented as a peripheral cue shortly before the appearance of a ring of 12 letters. Subjects were required to report the identity of the first target and the orientation of the lone T in the ring. At all target–probe lags (of 90, 270, or 630 msec), subjects consistently showed higher accuracy in orientation discrimination when the T appeared at cued locations (where the square had been presented) than when it appeared at uncued locations. The finding that the cuing effect induced by onsets survived the AB is consistent with the traditional idea that the involuntary

orienting elicited by onsets is effortless, demanding only a negligible amount of attentional resource.

However, there is still debate regarding the extent to which attentional capture caused by onsets is truly automatic. A few recent studies have challenged the traditional opinion by showing that attentional capture by abrupt onsets can be interrupted by a concurrent monitoring task. For example, Boot, Brockmole, and Simons (2005) found that abrupt onsets failed to capture attention in visual search when subjects had to perform a concurrent auditory one-back task. Another recent study (Santangelo, Olivetti Belardinelli, & Spence, 2007) showed that both reflexive visual and auditory orienting were disrupted when subjects were instructed to attend to an RSVP or RSAP stream.

There is clearly a discrepancy between the results of Ghorashi et al. (2007) on one hand and Boot et al. (2005) and Santangelo et al. (2007) on the other. How can we reconcile the discrepancy? One possibility is that a concurrent dual task differs from an AB task. In particular, the dual task requires continuous engagement of attention to the primary task, whereas AB depletes attention only for a brief period of time. This difference could account for the intact cuing effect observed at longer target–probe lags in the Ghorashi et al. study. However, it is still necessary to explain the unimpaired cuing effect at lags of 1 and 3, presumably during the time at which the AB was the strongest.

There is also another explanation for the apparently discrepant results across studies: This alternative explanation originates from previous studies that focused on top-down control of onset capture. Although some studies (Jonides, 1981; Schreij, Owens, & Theeuwes, 2008) showed that onset capture often shows resistance to subjects' intention, many recent studies have confirmed that onset capture is subject to top-down control. For example, Folk, Remington, and Johnston (1992) found that onsets of uninformative cues captured attention only if subjects were required to detect an onset target but not when subjects were looking for a target in a designated color (see also Gibson & Kelsey, 1998). Similarly, abrupt onsets of

distractors fail to capture attention if the distractors do not share the sought-for target color (Du & Abrams, 2008; Folk, Leber, & Egeth, 2002). Spatial certainty can also exert top-down control on onset capture. For instance, a recent study (Christ & Abrams, 2006) indicated that peripheral onsets can be ignored if subjects fixate in advance at the target location.

Given the preceding examples of the modulation of reflexive orienting by voluntary mechanisms, it is possible that the intact cuing effect during the AB in the Ghorashi et al. (2007) study was actually caused by a combined effect of both reflexive and voluntary orienting to the location of the onset. This is possible because, in Ghorashi et al., the lowest level of cue validity (14.3%) was still higher than chance (8.3%). Thus, it would have been advantageous for subjects to voluntarily attend to the location of the cue. As a result, the benefit of cues presented during the AB may have arisen from a combined effect of both reflexive and voluntary orienting, not from purely involuntary orienting.

In the present study, we aimed to clarify whether involuntary orienting induced by irrelevant onsets is insensitive to available attentional resources. This amounts to a test of the *load-insensitivity criterion* of automaticity (Jonides, 1981). In particular, if capture is automatic, it should not depend on the concurrent attentional load. Instead of using a concurrent dual task, we examined whether involuntary orienting is immune to the AB. We chose the AB paradigm because it provides two ways to easily manipulate the available attentional resources: by varying the target-probe lag and by varying the difficulty in selecting the first target.

EXPERIMENT 1

Because the peripheral cues in the Ghorashi et al. (2007) study were at least partially informative, the intact cuing effect in their study might be due in part to voluntary control and not exclusively to involuntary orienting. The present experiment was a conceptual replication of Ghorashi et al. with the addition of several changes designed to eliminate any voluntary orienting component. First, after presentation of an exogenous cue in either the left or the right visual hemifield, a single peripheral probe letter was presented (instead of a search array of 12 letters, as was done by Ghorashi et al.). With only a single letter, there would be no reason for subjects to rely on cues to help locate it. Second, the probe letter was equally likely to appear either in the cued hemifield or in the uncued hemifield. Thus, cue validity was 50%, and the exogenous cues were completely uninformative with respect to the probe's location. Finally, all subjects were explicitly informed of the cue validity and instructed to ignore the cues.

Besides the aforementioned differences between our method and that of Ghorashi et al. (2007), there was another key change. In particular, we made the first task easier by instructing subjects to discriminate the sole green letter (either A or B) in the RSVP stream. Such an easy first task would be expected to have minimal attentional demands. Presumably, if involuntary orienting elicited by

onsets is really immune to the AB effect, an exogenous cuing effect is more likely to remain intact in the present experiment than in Ghorashi et al.

Method

Subjects. Twenty-five undergraduates each participated in a 30-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 Figure 1. Each trial began with a 600-msec presentation of a gray fixation cross in the center of the black screen, followed by the sequential presentation of up to 18 uppercase letters at the center. The letters were selected randomly without replacement from the English alphabet, excluding *I*. Letters were 1.3° in width and 1.6° in height. Each letter was presented for 50 msec, followed by a 50-msec blank interval, yielding a stimulus onset asynchrony (SOA) of 100 msec. All of the subjects were required to report the sole green letter (either A or B) in the sequence. Across trials, the green target letter appeared in the 10th–12th frame of the letter sequence. The colors of the remaining letters, including the probe letter in the periphery, were all gray. The single probe letter appeared at lag 2, lag 3, or lag 7 (200, 300, or 700 msec after the onset of the first target) with equal probability. The inner edge of the probe letter appeared either 9° to the right or 9° to the left of the central fixation point (equally often). The probe letter could be any letter except A or B. An open box (1.8° square) served as an exogenous cue and always appeared 100 msec before the probe letter, 5.7° either to the left or to the right of fixation, with equal probability. For half of the trials, the probe letter appeared in the hemifield in which the cue had appeared; thus, those were *validly cued* trials. The other trials were *invalidly cued* trials, in which the cue and probe letter appeared in opposite hemifields. Subjects reported the identities of

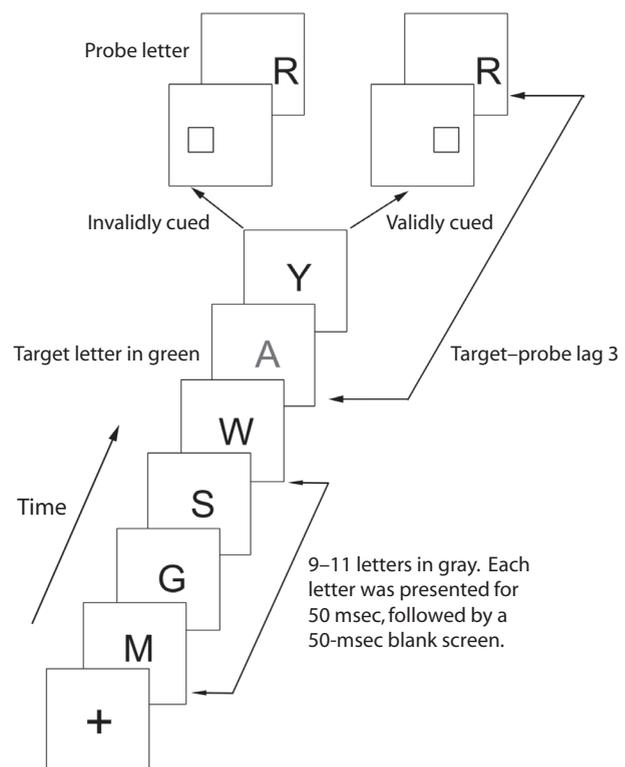


Figure 1. A schematic representation of the procedure in Experiment 1.

the target letter and probe letter by pressing keys after each trial, with equal emphasis on the two tasks.

Design. Each trial used one of three target–probe lags (lag 2, lag 3, or lag 7) and two cue-validity conditions (validly or invalidly cued). The experiment contained 20 replications of each combination of the two cue validity conditions and the three target–probe lags, for a total of 120 trials, presented in a random order. Subjects were apprised of the fact that the target locations were not correlated with the cue locations. They first served in one block of 24 trials for practice. They received a brief break after 60 test trials.

Results and Discussion

The average accuracy for the first target collapsed across all lags and cue validity was .99. Accuracy data were submitted to an ANOVA, which revealed no effects of cue validity or target–probe lag. Thus, the exogenous cue had no influence on identification of the first target.

The accuracy of identification of probe letters (the second target), given that the first target is correctly reported, is plotted in Figure 2 as a function of cue validity and target–probe lag. First, we found a significant main effect of lag, with higher accuracy at longer lags [$F(2,48) = 4.96, p < .05$]. The fact that probe identification suffered at short lags indicates the existence of the AB.¹ Next, there was a significant main effect of cue validity, with higher accuracy when the cue was valid than when the cue was invalid [$F(1,24) = 5.49, p < .05$]. Most important, the interaction between lag and cue validity was significant [$F(2,48) = 4.22, p < .05$]. As can be seen in Figure 2, a valid cue improved probe identification only at the two longest target–probe lags but not at lag 2, when perception was most likely to be affected by the AB. Simple effects tests revealed no cuing effect at lag 2 [$F(1,24) < 1$] but significant cuing effects at lag 3 [$F(1,24) = 11.39, p < .005$] and at lag 7 [$F(1,24) = 4.75, p < .05$]. Thus, involuntary orienting caused by an uninformative onset was susceptible to the effects of the AB.

The AB differs from a concurrent dual task in such a way that the AB only depletes attention for a short period of time during each trial, whereas a concurrent dual task requires sustained engagement of attention for a more prolonged duration. However, Experiment 1 shows that even the time-limited attentional demands of a relatively easy AB task are capable of reducing the impact of an exogenous cue. These findings contrast with those of Ghorashi et al. (2007), who found an intact cuing ef-

fect during the blink time of the AB. Given the spatial uncertainty of probe letter appearance in Ghorashi et al.'s search task and the partially informative value of the cue, voluntarily orienting to the onsets was always a reasonable strategy. Therefore, their intact cuing effect might have reflected at least a partial effect of voluntary orienting or perhaps a synergistic effect of voluntary and involuntary mechanisms (Du & Abrams, 2008). Regardless of the explanation, the present results clearly show that exogenous cuing is indeed reduced when the cue appears during the blink time of the AB.

The fact that exogenous cuing returned as the target–probe lag increased indicates that involuntary orienting was only disrupted for a short period, when the AB was most severe. More important, this pattern suggests that involuntary orienting caused by an uninformative onset was sensitive to the manipulation of available attentional resources. Such sensitivity to the available attentional resources indicates that involuntary orienting to sudden onsets is at least somewhat attention demanding and, as a result, fails the load-insensitivity test of automaticity.

In Experiment 1, because the first target was a salient color singleton, it was very easy to detect, and, as a result, the severity of the AB was probably quite minimal and short lived. Furthermore, one might question the apparent absence of AB in the invalid condition. In that condition, there was no direct evidence of the AB in the data (such as an increase in accuracy with increasing lag). Presumably, the AB was generated in both conditions, but its presence in the invalid condition was masked by our presentation of a 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 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 there was never any exogenous cue presented (thus, target–probe 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 accuracy of probe identification did indeed increase with increasing lag [.55 for lag 2, .63 for lag 3, and .66 for lag 7; $F(2,28) = 5.0, p < .05$]. This pattern indicates that the AB is generated by our procedure.

Because the ease of target detection resulted in a relatively small (yet significant) AB, we next sought to increase the difficulty of the first task to further reduce the available attentional resources. We expected to observe a more prolonged suppression of the exogenous cuing effect, further revealing the reliance of involuntary exogenous cuing on attentional resources.

EXPERIMENT 2

The first task in Experiment 1 was to detect a color singleton, which is presumably not very attention demanding. However, even such an easy task produced an AB and succeeded in reducing exogenous cuing at the shortest target–probe lag. If the reduction in exogenous cuing

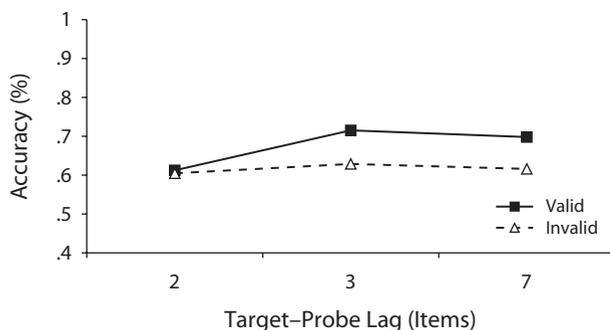


Figure 2. Accuracy of probe letter identification in Experiment 1.

did indeed extend from the demands of the first task, an increase in first-task difficulty would be expected to produce a prolonged reduction in the cuing. That idea was tested in Experiment 2.

There is another reason to modify the first task used in Experiment 1. The task used in Experiment 1 required detection of a color singleton, and it is known that both color singletons and onsets capture attention in a stimulus-driven way (Lamy & Egeth, 2003; Theeuwes, 1994). Therefore, it is possible that the reduced exogenous cuing in Experiment 1 was actually due to some specific competition between singleton capture and onset capture and not to a depletion of more general attentional resources caused by the first task. In order to rule out that possibility, we set up the first task here so that it did not require stimulus-driven capture.

To accomplish those two purposes, in the first task here, subjects were required to report the identity of a gray target letter (either an A or B) in an RSVP stream that consisted entirely of gray letters. Not only is this task more difficult than identification of a color singleton, but it also does not rely on stimulus-driven mechanisms. If involuntary orienting elicited by onsets is truly attention demanding, the first task here should produce a more prolonged reduction of exogenous cuing than did that in Experiment 1.

Method

Subjects. Twenty-three students each participated in a 30-min session for course credit. All had normal or corrected-to-normal visual acuity.

Apparatus, Procedure, and Design. The first target in the present experiment was a gray letter, either A or B, embedded in an RSVP stream of gray letters. For the first task, subjects were to indicate whether an A or a B had been presented. All other aspects of the experiment were exactly the same as those in Experiment 1.

Results and Discussion

The average accuracy for the first target collapsed across all lags and cue validity was .97. Accuracy data were submitted to an ANOVA, which revealed no effects of cue validity or target–probe lag. Thus, the exogenous cue had no influence on identification of the first target.

The accuracy of identification of the probe letter, given that the first target is correctly identified, is plotted in Figure 3 as a function of cue validity and target–probe

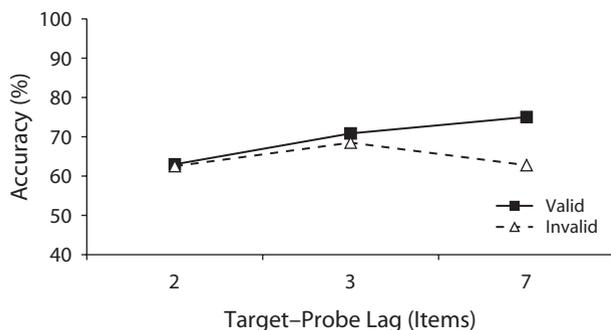


Figure 3. Accuracy of probe letter identification in Experiment 2.

lag. First, we again found a significant main effect of lag, indicating the existence of an AB [$F(2,44) = 4.41, p < .05$]. Next, there was a significant main effect of cue validity, with higher accuracy when the cue was valid as opposed to invalid [$F(1,22) = 4.50, p < .05$]. But most important, the interaction between lag and cue validity was significant [$F(2,44) = 3.85, p < .05$]. A further simple effect test revealed no exogenous cuing effect at lag 2 or lag 3 [$F_s(1,22) < 1$] but a large exogenous cuing effect at lag 7 [$F(1,22) = 10.94, p < .005$]. This pattern again suggests that the exogenous cuing effect caused by onsets was eliminated at the two short target–probe lags but not at the longer lag.

The results of Experiment 2 replicated those of Experiment 1, showing a reduced exogenous cuing effect when the AB was strong (at short lags). This again shows that involuntary orienting of attention was impaired by the attentional demands of processing the first target. Relative to Experiment 1, we also found a prolonged suppression of the exogenous cuing effect—with the impact of the AB occurring at both lag 2 and lag 3. We attribute this increased effect of the AB to the increased difficulty of the first task (to identify whether an A or a B was presented) compared with that of Experiment 1 (to identify the sole green letter). This finding is important because it indicates that involuntary orienting elicited by a sudden onset is sensitive to the manipulation of the available attentional resources. It is also noteworthy that the first task in Experiment 2 did not rely on stimulus-driven orienting mechanisms like the detection of the color singleton in Experiment 1. Thus, the interference with exogenous cuing can be attributed to a depletion of general attentional resources and not specifically to competition among stimulus-driven mechanisms.

GENERAL DISCUSSION

In two experiments, we showed that the exogenous cuing effect induced by uninformative cues was reduced during the AB. Because involuntary orienting caused by abrupt onsets was susceptible to the attentional demands imposed by the AB, we conclude that such orienting is not entirely automatic. In particular, onset capture fails the load-insensitivity criterion of automaticity. Note that onsets do indeed appear to satisfy the resistance-to-suppression criterion (Christ & Abrams, 2006). Our findings are consistent with previous results that showed that involuntary orienting caused by onsets was impaired by a concurrent dual task (Boot et al., 2005; Santangelo et al., 2007). In addition, the fact that the exogenous cuing effect only suffered at short target–probe lags (lag 2 in Experiment 1 and lags 2 and 3 in Experiment 2) and recovered at longer lags further indicates that involuntary orienting was sensitive to the manipulation of available attentional resources (attentional resources recover as target–probe lag increases). The sensitivity of involuntary orienting to the AB and our ability to modulate the impact on orienting by manipulating the difficulty of the AB task provide compelling evidence against claims that involuntary orienting is automatic. Instead, it seems clear that involuntary orienting in response

to an exogenous peripheral stimulus depends on the availability of limited attentional resources.

The present study is the first showing that involuntary orienting caused by abrupt onsets suffers during the AB. These results differ from those in Ghorashi et al. (2007). One possible explanation for the discrepancy is that different probe tasks were used. In the Ghorashi et al. study, a visual search task was used as the probe task. The high degree of spatial uncertainty in that case might have provided incentive for subjects to use the peripheral cues voluntarily. On the contrary, we asked subjects to identify a single peripheral letter as the probe task. This probe task itself rendered the exogenous cues useless, because subjects could always rely on the onset of the probe letter to guide their spatial attention. Alternatively, the intact cuing effect in Ghorashi et al. might have arisen as a result of their use of a slightly informative peripheral cue. In our experiments, we set the exogenous cues to be completely uninformative and explicitly instructed subjects to ignore them, which further discouraged subjects from using them voluntarily.

The present experiments cannot distinguish between the two possibilities, but both possibilities involve voluntary mechanisms. Therefore, our results, along with Ghorashi et al.'s (2007), actually indicate that involuntary orienting driven by onsets is disrupted by the AB, whereas a combined effect of both involuntary and voluntary orienting provides a much stronger resistance to disruption. This is consistent with previous studies that showed that a synergistic effect between stimulus-driven salience and top-down control is actually stronger than the individual effects of either stimulus-driven salience or top-down selection in isolation (Du & Abrams, 2008; Ludwig & Gilchrist, 2003).

In summary, involuntary orienting elicited by uninformative onsets can be suppressed by the AB. This indicates that, with respect to the load-insensitivity criterion of automaticity, involuntary orienting is not automatic but, instead, relies on limited attentional resources.

AUTHOR NOTE

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NOTE

1. The often-observed sparing of AB-induced impairment at lag 1 would not necessarily be expected to occur here. This is because our task differs from the typical AB task in that (1) an exogenous cue was always presented shortly before the second target and (2) the second target was in the periphery, not in the central RSVP stream. Additionally, the sparing is typically observed at a lag of 1, but the shortest lag tested here was 2. Finally, the lag 1 sparing of the AB has been shown to be eliminated when spatial attention shifts occur, as in the present experiments (Visser, Bischof, & Di Lollo, 1999).

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