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Abrupt Onsets Cannot Be Ignored

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Participants identified target letters at cued locations in the presence of occasional abrupt onsets of new distracter letters. The onsets distracted the participants and impaired their letter-identification performance despite confirmation that participants were using the information provided by the cue. That result contrasts with earlier results by other researchers that revealed an ability of participants to ignore abrupt onsets in some cases. Our results, however, were obtained under conditions that prevented anticipatory eye movements to the target, unlike the earlier methods. In a subsequent experiment when participants were permitted to look at the target in advance, the distracting effect of the onsets was eliminated, suggesting that participants may have looked at the target in the earlier studies. We conclude that abrupt onsets cannot be ignored unless the target element is conferred a substantial advantage via fixation.

Researchers interested in stimulus-driven attentional capture have found that the appearance of an abrupt onset is one of the few stimuli that seem to capture attention even in the absence of a top down expectation. For example, Irwin, Colcombe, Kramer, and Hahn (2000) found that participants were 51 ms slower to identify target letters when an irrelevant onset appeared in the display, suggesting that abrupt onsets diverted attentional resources from the letter identification task. Nevertheless, even abrupt onset appearance does not satisfy the "resistance to suppression" criterion of stimulus-driven capture. That criterion is satisfied only when an observer is unable to suppress the effects of a particular stimulus under any circumstance. Two laboratories have shown that it is possible for participants to successfully ignore abrupt onsets under some circumstances (Theeuwes, 1991; Yantis & Jonides, 1990). To date, only motion onsets appear unable to be suppressed (Christ & Abrams, 2005).

Of note, the few studies mentioned that have explored the ability to ignore abrupt onsets did so under conditions in which participants were free to move their eyes around the display.[1] As a result, because participants were provided with mostly valid cues as to the target's location, it is possible that participants chose to fixate the target in advance on some or most of the trials in the experiments. If participants fixated the target, they could benefit from the greater resolution at the fovea, and they would also be able to focus attention very narrowly on the target region. Under such conditions the ability to ignore the appearance of an abrupt onset in the periphery would not seem so surprising. In the present paper, we reexamined the ability of participants to ignore abrupt onsets under conditions in which we monitored eye position. To anticipate the results, we found that participants are not capable of ignoring abrupt onsets when they are forced to maintain fixation at the center of the display.

Experiment 1

In our first experiment we had participants identify letters that appeared in a pre-specified location while, on some trials, a new letter appeared in a non-target location. During the experiment we monitored participants' eye position to ensure that they remained fixated at the center of the display prior to presentation of the target. If indeed it is possible for participants to ignore abrupt onsets when the target location is known, then we should obtain the same results here that were obtained by earlier researchers who have examined this issue but without eye position monitoring (Theeuwes, 1991; Yantis & Jonides, 1990).

Method

Participants. Eleven naïve undergraduate students served as participants in a single 40-minute session in exchange for course credit. All had normal or corrected-to-normal vision.

Apparatus & Procedure. Participants were seated 34 in (86.4 cm) from a CRT display in a dim, sound-attenuated room. Each trial began with a preview display that consisted of a small centrally-located pointer and 3 figure-eight placeholders. Each placeholder was 2º high and 1º wide. The placeholders were arranged equidistant around an imaginary circle 12º in diameter and centered on the middle of the display. The pointer indicated the placeholder that would subsequently contain the target (100% predictive). Following a 1500 ms delay, the pointer was replaced by a fixation dot. Five hundred milliseconds later, two line segments were removed from each placeholder to reveal the search display.[2] On half of the trials, coincident with presentation of the search array, an additional letter appeared in a previously unoccupied location equidistant between two of the pre-existing items. The search display always contained either an S or an H, and participants pressed one of two keys as quickly as possible to indicate the letter that was present. The existing non-target locations and the "abrupt onset" contained either a U, E, or P. (The abrupt onset never contained the target.) The sequence of events on a trial in which an abrupt onset appeared is illustrated in the upper panel of Figure 1.

Participants were requested to maintain fixation at the center of the display throughout trial presentation, and eye position was monitored to ensure compliance. A chinrest was used to steady the participants' heads, and eye position was monitored using a video-based eye movement monitor (ISCAN Model RK-426PC, Cambridge, MA).3 Trials during which a participant's continued fixation could not be verified were excluded from further analyses.

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The number of trials excluded on this basis (Overall mean = 11.1 %) did not differ based on condition, $t(10) = 1.24$, $p > .05$.

The search display remained visible until the participant responded or 3000 ms had elapsed. If the participant responded incorrectly, a brief tone followed by the message "Wrong Response" was presented. A tone and relevant message (i.e., "Too Early" or "Too Slow") was presented if a participant responded less than 300 ms after display onset or failed to respond within 3000 ms, respectively. If continued fixation throughout the trial could not be verified, a tone and "Eye Movement Detected" were presented.

Design. Following 24 practice trials, participants served in 216 experimental trials. Trial presentation was balanced such that the target was equally likely to appear in each of the three placeholders, the abrupt onset was equally likely to appear between any two placeholders, the distracter letters were equally likely to be U, E, or P, and the target letter was equally likely to be S or H. The configuration of the three elements in the display was randomly selected and had elements at positions of 30, 150, 270 degrees around fixation (as seen in the example in Figure 1) or positions of 90, 210, and 330 degrees around fixation. The target-to-response key mapping was counterbalanced across participants. Trial types were randomly mixed. At intervals of 36 trials, participants were given the opportunity to take a break.

Results and Discussion

Mean reaction times for each condition are shown in Figure 2. Participants were 42 ms slower to identify the target letter when an abrupt onset appeared in the display (Mean RT = 773 ms) as compared to when an abrupt onset did not appear (Mean RT = 731 ms), $t(10) = 3.11$, $p < .05$. Error rates were low (Overall mean = 3.5 %) and did not depend on the condition, $t(10) < 1$, $p > .05$.

Thus, participants were unable to ignore the abrupt onsets despite the fact that they had complete certainty regarding the target location. The results suggest that abrupt onsets may exert a more powerful effect than previously believed. However, our results are inconsistent with findings of other researchers who conducted similar experiments. In particular, Yantis and Jonides (1990) and Theeuwes (1991) each found that participants were indeed able to ignore abrupt onsets when the location of the target was known with certainty in advance, as in our experiment. Before exploring a potential explanation for the discrepant results, we turn to an ancillary issue.

Experiment 2

An alternative explanation exists for the results from Experiment 1. It is possible that the participants chose to ignore the information provided by the arrow cue. If that had been the case then they might have simply allocated their attention diffusely over the entire display. As a result, an abupt onset anywhere in the display could have been distracting, as we found. To eliminate that possibility, we repeated the experiment here along with a manipulation designed to motivate the participants to use the information provided by the cue, and the capability to confirm that participants were indeed using the information.

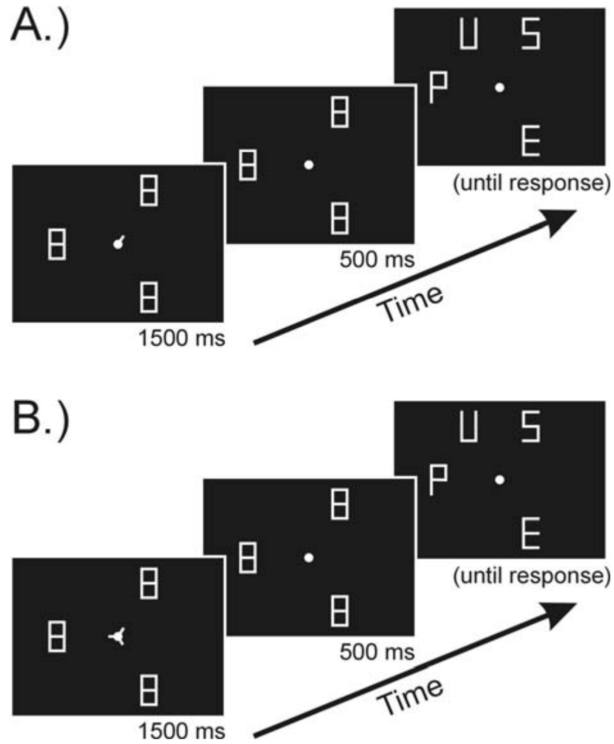

Figure 1. Sequence of events on an abrupt onset trial in Experiments 1 (top panel only) and 2, shown separately for the pointer-informative condition (top panel) and the pointer-uninformative condition (bottom panel).

Method

Subjects. Twenty two naïve undergraduates who had not served previously were selected from the same population as that in Experiment 1. Each served in one 40-minute session in exchange for course credit.

Apparatus & Procedure. This experiment was very similar to Experiment 1, with differences noted here. On half of the trials, the pointer indicated the placeholder that would subsequently contain the target (100% predictive; as in Experiment 1). For the other half of the trials, the pointer was uninformative and pointed to all three placeholders at once (0% predictive). As in Experiment 1, an abrupt onset also appeared on half of the pointer-informative trials and on half of the pointer-uninformative trials. The sequence of events on pointer-informative and pointer-uninformative trials in which an abrupt onset appeared is shown separately in Figure 1.

Eye position was monitored, and trials during which central fixation could not be verified were excluded from further analysis. The number of trials excluded on this basis (Overall mean = 9.1 %) did not differ based on condition, all F's < 1, p's > .05.

Participants were verbally encouraged to utilize the predictive nature of the pointer (when informative) to enhance their task performance. In addition, we implemented an extensive trial-by-trial feedback system designed to elicit optimal performance (i.e., fast response times and low error rates) throughout the experiment. The present feedback system was similar to those that have been used in the past to motivate participants during visual search experiments (e.g., Derryberry & Reed, 1994).

After each trial, a participant was given feedback based on their response accuracy and response time. If the participant responded incorrectly, a brief 100 Hz tone followed by the message "Wrong Response, -10 points" was presented. A 100 Hz tone and the message "Too Early, -10 points" were presented if a participant responded less than 150 ms after display onset. If continued fixation throughout the trial could not be verified, a 100 Hz tone and "Eye Movement Detected" were presented (no point deduction).

For purposes of providing feedback on the remaining trials, a criterion RT was calculated. In the practice blocks, the criterion RT was set equal to 600 ms. In all subsequent blocks, the criterion RT was set equal to the median RT of all correct responses from the previous same-condition (i.e., pointer-informative or pointer-uninformative) block of trials. If the participant's RT was slower than the criterion, then a 100 Hz tone and the message "XXX" were presented (no point deduction). If the participant's RT was faster than the criterion, then 300 Hz and 600 Hz tones were presented along with the message "+10 points." Participants were encouraged to earn as many points as possible while minimizing the amount of points lost. After each block of trials, participants were given summary information about their performance on the preceding block (i.e., number of points earned in the preceding block, total points earned overall). Between blocks, the experimenter also entered the testing room to record the summary values from the previous block on a log sheet and to provide additional verbal encouragement to the participant.

Design. Following 36 practice trials (a block of 18 pointer-informative trials and a block of 18 pointer-uninformative trials), participants served in 180 experimental trials. The pointer-informative and pointer-uninformative trials were presented in alternating blocks of 36 trials. Half of the participants received a block of pointer-informative trials first; the other half of the participants received a pointer-uninformative block first.

Results and discussion

Mean reaction times for each condition are shown in Figure 2. The data were analyzed using a 2 (abrupt onset—present or absent) X 2 (pointer—informative or uninformative) repeated measures ANOVA. First note that participants were considerable faster in the pointer-informative conditions compared to pointer-uninformative conditions [$F(1, 21) = 36.00$, $p < .001$]. This shows that the participants were indeed using the information provided by the pointer. Note also that the overall reaction times are quite fast for the two-choice identification task that we used, suggesting further that our methods provided an effective incentive for the participants. Next, note that reaction times were slower when an abrupt onset appeared in the display [$F(1, 21) = 70.46$, $p < .001$], indicating that participants were unable to ignore the abrupt onsets overall, replicating our earlier result. The effect of the abrupt onset was numerically smaller under pointer-informative conditions (22 ms) as compared to the pointer-uninformative conditions (35 ms), but not reliably so [$F(1, 21) = 3.30$, $p > .05$ for the interaction]. Importantly, when the pointer-informative condition was analyzed in isolation, abrupt onsets had a significant effect [$t(21) = 4.53$, $p < .001$). The present results show that even under conditions in which motivated participants focus their attention on the known target location, an abrupt onset elsewhere in the display impairs target identification performance. Thus abrupt onsets appear to satisfy the resistance-to-suppression criterion for attentional capture.

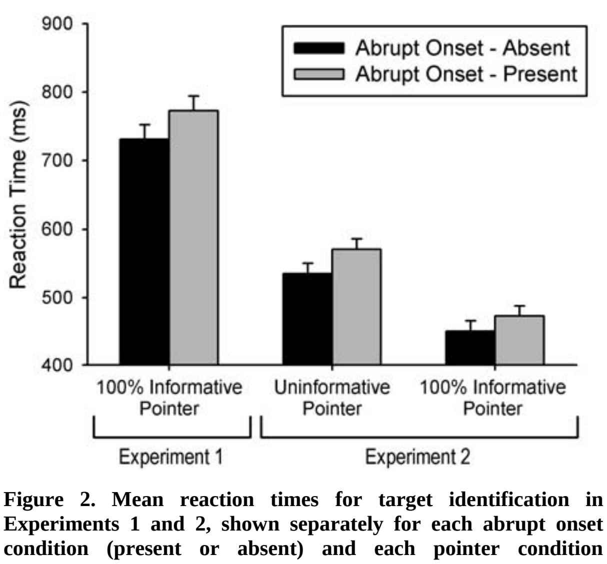

Figure 2. Mean reaction times for target identification in Experiments 1 and 2, shown separately for each abrupt onset condition (present or absent) and each pointer condition (informative or uninformative). Error bars represent 95% confidence intervals.

These findings are further supported by the error rate analysis. Participants were more likely to make an error in the pointer-uninformative conditions (Mean error rate = 10.0%) compared to pointer-informative conditions (Mean error rate = 5.9%) [$F(1, 21) = 33.93$, $p < .001$]. Error rates were also higher when an abrupt onset appeared in the display (Mean error rate = 8.8%) compared to when one did not appear (Mean error rate = 7.2%) [$F(1, 21) = 5.04$, $p < .05$]. The interaction was not significant [$F(1, 21) < 1$, $p > .05$].

Experiment 3

We now turn to an investigation of the reason for the discrepancy between our results and those of earlier researchers. In the earlier studies (Theeuwes, 1991; Yantis & Jonides, 1990), participants had been asked to maintain fixation at the center of the display, but because eye movements were not monitored, it is not possible to confirm that participants complied with the request. Indeed, previous research suggests that verbal instructions alone are often not sufficient to insure that participants are maintaining central fixation (Jordan, Patching, & Milner, 1998).

As noted earlier, if participants in the Theeuwes (1991) and Yantis and Jonides (1990) studies had instead fixated upon the target location rather than a central location, then the target would receive a substantial benefit over the abrupt onset in terms of enhanced retinal resolution. Furthermore fixation of the target might facilitate the narrow focusing of attention on the target, perhaps making it much easier to resist the deleterious effects of the abrupt onset appearance.

We tested that possibility in the present experiment by including trials on which participants were required to look at the target in advance, and trials on which participants were prohibited from looking at the target (as in our earlier experiments).

In addition, the stimuli used in Experiments 1 and 2 were very similar to those utilized by Yantis and Jonides (1990). To explore the extent to which our findings could be generalized to other types of stimulus displays, in the present experiment we adopted methodology that was more similar to that employed by Theeuwes (1991).

Method

Subjects. Sixteen naïve undergraduate students served as participants in a single 40-minute session in exchange for course credit. All had normal or corrected-to-normal vision.

Apparatus & Procedure. Each trial began with a preview display that consisted of a centrally-located fixation dot and 4 figure-eight placeholders. Each placeholder was 1º high and 0.5º wide. The placeholders were arranged at the corners of an imaginary square 8º in height/width and centered on the middle of the display. After 400 ms, the fixation dot was replaced by a pointer that indicated the soon-to-be location of the target. Following a 600 ms delay, two line segments were removed from each placeholder to reveal the search display. On half of the trials, coincident with presentation of the search array, a solid white square 0.5º in height/width appeared 1º to the peripheral side of one of the letters to be searched. The search display always contained either an S or an H, and participants pressed one of two keys as quickly as possible to indicate the letter that was present. The existing non-target locations contained either a U, E, or P. The sequence of events on a trial in which an abrupt onset appeared is illustrated in Figure 3.

Half of the participants were requested to maintain fixation at the center of the display throughout trial presentation. The other half of participants were instructed to shift their gaze to the indicated location once the pointer appeared. Eye position was monitored to ensure compliance, and trials during which appropriate fixation could not be verified were excluded from further analysis. The number of trials excluded on this basis (Overall mean = 5.3 %) did not differ based on condition, all *p*'s > .05.

The search display remained visible until the participant responded or 3000 ms had elapsed. As in Experiment 1, feedback was given if the participant responded too quickly, too slowly, or incorrectly. If appropriate fixation and eye movement could not be verified, a tone and "Bad Eye Movement" were presented.

Design. Following 24 practice trials, participants served in 320 experimental trials. Trial presentation was balanced such that the target was equally likely to appear in each of the four placeholders,

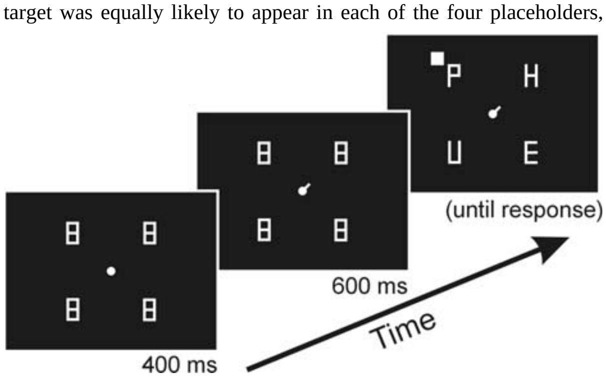

Figure 3. The sequence of events on an abrupt onset trial in Experiment 3.

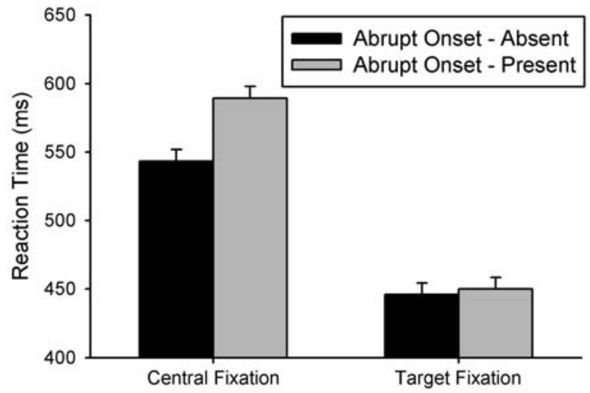

Figure 4. Mean reaction times for target identification in Experiment 3, shown separately for each abrupt onset condition (present or absent) and each eye fixation condition (central or target). Error bars represent 95% confidence intervals for the within subjects effect and interaction.

the abrupt onset was equally likely to appear near any placeholder, the distracter letters were equally likely to be U, E, or P, and the target letter was equally likely to be S or H. The target-to-response key mapping and fixation condition (central fixation versus target fixation) were counterbalanced across participants. Trial types were randomly mixed. At intervals of 64 trials, participants were given the opportunity to take a break.

Results and discussion

Mean reaction times from each condition are shown in Figure 4. As can be seen in the figure, when central fixation was confirmed, participants could not ignore the abrupt onset, as was the case in Experiments 1 and 2; thus confirming that our findings could be generalized to stimuli and timing similar to that used by Theeuwes (1991). Of note, when participants fixated on the target, however, the effect of the abrupt onset was eliminated.

Inferential statistics support these claims. The data were analyzed using mixed model ANOVA with abrupt onset condition (present or absent) serving as a within subjects factor and location of fixation (central or target) serving as a between subjects factor. Participants were generally faster to identify the target when it was fixated, $F(1, 14) = 4.91$, $p < .05$. In addition, participants were slower to respond when an abrupt onset appeared, $F(1, 14) = 20.52$, $p < .001$. Of most interest, a significant interaction between eye fixation condition and abrupt onset condition was also observed, $F(1, 14) = 14.30$, $p < .005$. Additional analyses revealed that the appearance of an abrupt onset slowed RT considerably (46 ms) when the participants maintained fixation at the center of the display, $t(7) = 4.42$, $p < .005$. However, an abrupt onset had little or no effect (4 ms) when the participants fixated the target, $t(7) = 1.10$, $p > .05$. Error rates were low (Overall mean

= 5.4%) and did not depend on the condition, all *p*'s > .05.

GENERAL DISCUSSION

Across three experiments and two different types of visual displays, we demonstrated that the appearance of an abrupt onset disrupts performance of a discrimination task, even when participants are attempting to maintain a highly focused attentional set elsewhere in the display. As such, the present results represent the first evidence that abrupt onsets may fulfill the "resistance to suppression" criterion of attentional capture (Jonides, Naveh-Benjamin, & Palmer, 1985; Palmer & Jonides, 1988; Yantis & Jonides, 1990). In other words, an individual does not appear to have voluntary control over the processes responsible for attentional capture by abrupt onsets.

The current findings contrast sharply with previous research that failed to find an effect of abrupt onsets under similar conditions. One possible explanation for this discrepancy is that participants in previous research have fixated the target location instead of maintaining central fixation (as instructed). Indeed, if one's goal was to minimize response time and maximize accuracy, it would be strategically beneficial for him/her to forego the experimenter's instructions and to fixate the target location. Unlike past studies, however, in the present study eye position was monitored and central fixation was confirmed during experimental trials.

Based on the present results, we conclude that the appearance of an abrupt onset cannot be fully ignored in that it continues to influence task performance despite an individual's intentions to the contrary. Future research is necessary to fully understand the nature of the influence (e.g., general filtering cost versus unintended spatial shift of attention) that abrupt onsets can have on the allocation of voluntary attention. Indeed, a number of factors (e.g, visual salience of the onset, frequency of onset occurrence) may play a role in this extent to which abrupt onsets "capture" attention. For example, recent findings by Neo and Chua (2006) suggest that abrupt onsets have a stronger influence on attention in situations where the onsets occur relatively infrequently as compared to situations where they are more commonplace.

In the present study, the abrupt onsets that we used also resulted in the appearance of a new object in the display. Because of this, our results may also bear on the large body of existing research (e.g., Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Irwin et al., 2000; Yantis & Hillstrom, 1994) documenting the significant influence that new objects can have on our moment-by-moment allocation of visual attention. A number of questions surrounding new objects and attention, however, still remain unresolved. For example, much like the real-world objects that we encounter on a day-to-day basis in our environment, the objects employed in the current experiments were defined by differences in luminance, and their appearance was accompanied by unique luminance transients. Whereas findings by Franconeri, Hollingworth, and Simons (2005) suggest that attentional capture by new objects may be contingent on the new object being coupled with a unique luminance transient, Davoli and Abrams (2005) found attentional capture by new objects even under conditions in which all items in the display (old and new objects alike) underwent identical luminance transients at the time of the new object's appearance. Future research will allow us to better discern the role that unique luminance transients and abrupt onsets play in capture of attention by new objects.

Of note, the appearance of an abrupt onset does not appear to be the only dynamic event whose attentional influences cannot be suppressed. Recently, we (Christ & Abrams, 2005) have reported that a pre-existing object that recently began moving continues to capture attention despite participants' attempts to maintain a focused attentional state elsewhere in their visual field. Why might abrupt onsets and new motion receive such high attentional priority? Although highly speculative, one possible explanation (e.g., Abrams & Christ, 2003; Franconeri & Simons, 2003; Yantis & Jonides, 1984) is that dynamic events such as these may signal the presence of a previously undetected living being (predator or prey) in our environment that requires immediate action.

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NOTES

1. Participants in the earlier studies were instructed to remain fixated, but fixation during the experimental trials was not monitored.

2. A relatively long time interval between the pointer and target display (i.e., 2000 ms) was used in order to insure that participants had sufficient time to fully focus attention prior to the target presentation. Of note, however, Yantis and Jonides (1990) utilized a much shorter time interval (i.e., 200 ms). To rule out the potential influence of this factor on the interpretation of the present results, we conducted a control experiment that was identical to Experiment 1 except that the time interval between the pointer and target presentation was 200 ms. The results were consistent with those of the present experiment. Namely, participants were slower to respond when an abrupt onset appeared in the display (Mean RT = 500 ms) as compared to when an abrupt onset did not appear (Mean RT = 479 ms), $t(7) = 3.01$, $p < .05$.

3. Prior to each block of trials, the eye movement monitor was calibrated by having the participant fixate at five points that were horizontally spaced at equal intervals across the visual display. A piecewise linear interpolation of the calibration points was then used to compute eye position. Immediately before each trial, the participant's eye position was sampled using the ISCAN monitor to ensure that he/she was fixated at the center of the display. If the participant failed to fixate correctly (within 2º of the fixation point), trial presentation would not begin until the participant complied. Once fixation was confirmed, trial presentation proceeded as described above. This is similar to the method that we have used previously (e.g., Christ, McCrae, & Abrams, 2002).