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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 distractor letters. The onsets distracted the participants and impaired their letter identification performance despite confirmation that they were using the information provided by the cue. This result contrasts with earlier results found 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. 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 receives 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 msec 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 (Theeuwes, 1991; Yantis & Jonides, 1990) have shown that it is possible for participants to successfully ignore abrupt onsets under some circumstances. To date, only motion onsets appear unable to be suppressed (Christ & Abrams, 2005).

It is worth noting that 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 to the target's location, it is possible that on some or most of the trials in the experiments, participants chose to fixate the target in advance. 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 study, we reexamined the ability of participants to ignore abrupt onsets while their eye positions were monitored. To anticipate the results: We found that participants are not capable of ignoring abrupt onsets when forced to maintain fixation at the center of the display.

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EXPERIMENT 1

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

Method

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

Apparatus and Procedure. The 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 three figure-eight placeholders. Each placeholder was 2º high and 1º wide. The placeholders were arranged equidistantly 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 1,500-msec delay, the pointer was replaced by a fixation dot. After 500 msec, 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 preexisting items. The search display always contained either an S or an H, and the participants pressed one of two keys as quickly as possible to indicate the letter that was present. The existing nontarget locations and the "abrupt onset" contained a U, an E, or a 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.

The participants were requested to maintain fixation at the center of the display throughout trial presentation, and eye position was

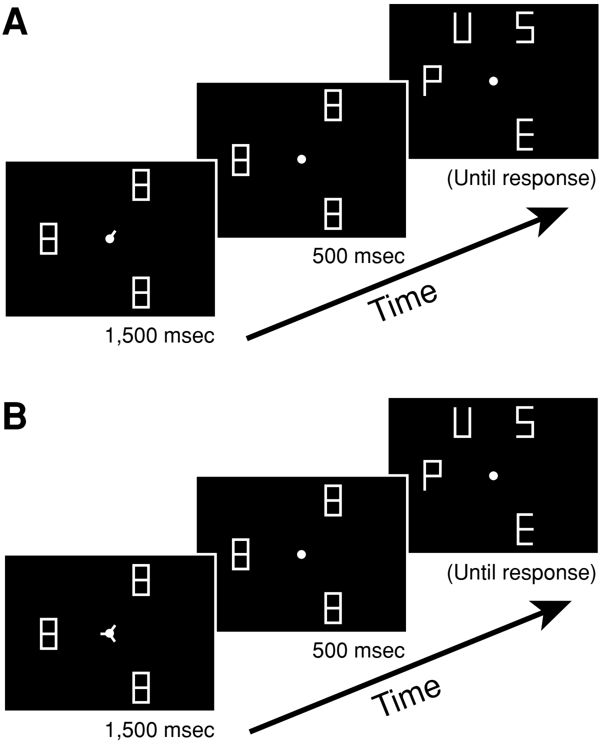

Figure 1. Sequence of events on an abrupt onset trial in Experiments 1 (top panel only) and 2, shown separately for the pointer-informative condition (top panel) and the pointer-uninformative condition (bottom panel).

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

The search display remained visible until the participant responded or until 3,000 msec had elapsed. If the participant responded incorrectly, a brief tone sounded, followed by the message "Wrong Response." A tone and relevant message (i.e., "Too Early" or "Too Slow") were presented if a participant responded less than 300 msec after display onset or failed to respond within 3,000 msec, respectively. If continued fixation throughout the trial could not be verified, a tone sounded and the message "Eye Movement Detected" was presented.

Design. Following 24 practice trials, the participants served in 216 experimental trials. Trial presentation was balanced in such a way 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 distractor 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 30º, 150º, and 270º around fixation (as seen in the example in Figure 1), or positions of 90º, 210º, and 330º around fixation. The target-to-response key mapping was counterbalanced across participants. Trial types were randomly mixed. At intervals of 36 trials, the participants were given the opportunity to take a break.

Results & Discussion

Mean reaction times (RTs) for each condition are shown in Figure 2. Participants were 42 msec slower to identify the target letter when an abrupt onset appeared in the display (mean RT = 773 msec) than they were when an abrupt onset did not appear (mean RT = 731 msec) [$t(10) = 3.11, p < .05$]. 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 being certain of 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: The participants may have chosen to ignore the information provided by the arrow cue. If so, they may have simply allocated their attention diffusely over the entire display. As a result, an abrupt onset anywhere in the display could have been distracting, as we found. To eliminate that possibility, we repeated the experiment, along with a manipulation designed to motivate the participants to use the information provided by the cue, and the capability to confirm that they were indeed using the information.

Method

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

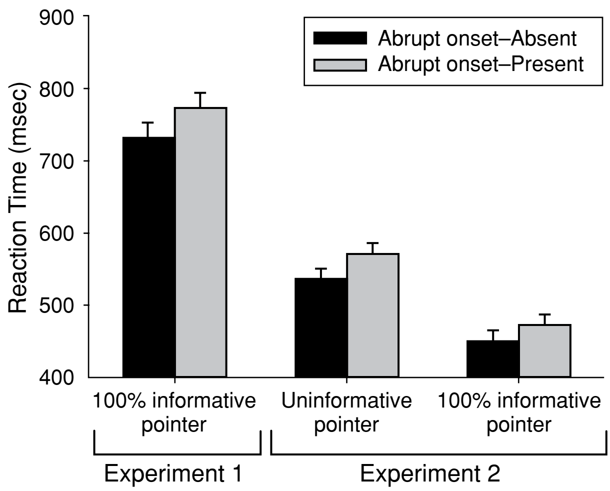

Figure 2. Mean reaction times for target identification in Experiments 1 and 2, shown separately for each abrupt onset condition (present or absent) and each pointer condition (informative or uninformative). Error bars represent 95% confidence intervals.

Apparatus and Procedure. This experiment was very similar to Experiment 1, with the 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 on the basis of condition (all Fs < 1, ps $> .05$).

The 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 RTs 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 (see, e.g., Derryberry & Reed, 1994).

After each trial, a participant was given feedback based on response accuracy and RT. If the participant responded incorrectly, a brief 100-Hz tone and the message "Wrong Response, −10 points" were presented. A 100-Hz tone and the message "Too Early, −10 points" were presented if a participant responded less than 150 msec after display onset. If continued fixation throughout the trial could not be verified, a 100-Hz tone and the message "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 msec. 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, a 100-Hz tone and the message "XXX" were presented (no point deduction). If the participant's RT was faster than the criterion, 300-Hz and 600-Hz tones were presented, along with the message "+10 points." The participants were encouraged to earn as many points as possible while minimizing the number of points lost. After each block of trials, the participants were given summary information about their performance on the preceding block (i.e., the 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 onto 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), the 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 RTs for each condition are shown in Figure 2. The data were analyzed using a 2 (abrupt onset: present or absent) × 2 (pointer: informative or uninformative) repeated measures ANOVA. First, note that participants were considerably faster in the pointer-informative conditions than in the pointer-uninformative conditions [$F(1,21) = 36.00$, $p < .001$]. This shows that the participants were indeed using the information provided by the pointer. Second, note also that the overall RTs are quite fast for the two-choice identification task that we used, further suggesting that our methods provided an effective incentive for the participants. Third, note that RTs 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; this replicates our earlier result. The effect of the abrupt onset was numerically smaller under pointer-informative conditions (22 msec) than under pointer-uninformative conditions (35 msec), 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 when 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.

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%) than in the 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%) than 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 (e.g., 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 ensure 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 fixated the target location rather than a central location, the target would have received 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 used 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

Participants. Sixteen experimentally naive undergraduate students served as participants in a single 40-min session in exchange for course credit. All had normal or corrected-to-normal vision.

Apparatus and Procedure. Each trial began with a preview display that consisted of a centrally located fixation dot and four 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 and width and centered on the middle of the display. After 400 msec, the fixation dot was replaced by a pointer that indicated the future location of the target. Following a 600-msec 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 and 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 the participants pressed one of two keys as quickly as possible to indicate the letter that was present. The existing nontarget locations contained a U, an E, or a 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 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 on the basis of condition (all *p*s $>$ .05).

The search display remained visible until the participant responded or until 3,000 msec 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 the message "Bad Eye Movement" were presented.

Design. Following 24 practice trials, the participants served in 320 experimental trials. Trial presentation was balanced in such a way that the target was equally likely to appear in each of the four placeholders, the abrupt onset was equally likely to appear near any placeholder, the distractor 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 vs. target fixation) were counterbalanced across participants. Trial types were randomly mixed. At intervals of 64 trials, the participants were given the opportunity to take a break.

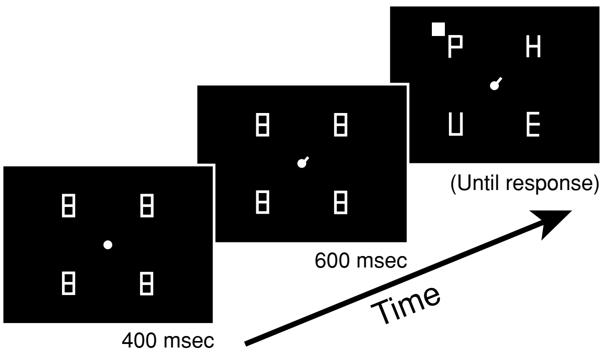

Figure 3. The sequence of events on an abrupt onset trial in Experiment 3.

Results & Discussion

Mean RTs 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 those used by Theeuwes (1991). Note, however, that when participants fixated the target, 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 was the fact that 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 msec) 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 msec) 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 display, we demonstrated that the appearance of an abrupt onset disrupts the 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 present 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 were to minimize response time and maximize accuracy, it would be strategically beneficial to ignore the experimenter's instructions and to fixate the target location. As was not the case in past studies, however, in the present study eye position was monitored and central fixation was confirmed during experimental trials.

On the basis of the present results, we conclude that the appearance of an abrupt onset cannot be fully ignored, in

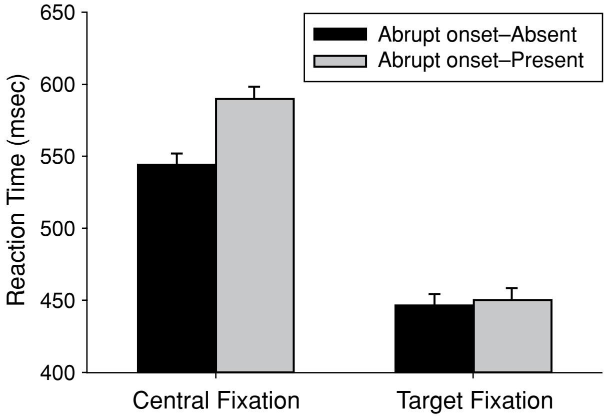

Figure 4. Mean reaction times for target identification in Experiment 3, shown separately for each abrupt onset condition (present or absent) and each eye fixation condition (central or target). Error bars represent 95% confidence intervals for the within-subjects effect and interaction.

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 vs. 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 and frequency of onset occurrence) may play a role in the extent to which abrupt onsets "capture" attention. For example, recent findings by Neo and Chua (in press) suggest that abrupt onsets have a stronger influence on attention in situations where such onsets occur relatively infrequently in comparison with 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 have a bearing 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. However, a number of questions about new objects and attention still remain unanswered. For example, much like the real-world objects that we encounter every day, the objects employed in the present 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's being coupled with a unique luminance transient, Davoli, Suszko, and Abrams (2005) found attentional capture by new objects, even when 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.

Note that 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) reported that a preexisting 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 predator or prey, requiring 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 interval between the pointer and target display (i.e., 2,000 msec) was used in order to ensure that the participants had sufficient time to fully focus attention prior to the target presentation. Note, however, that Yantis and Jonides (1990) used a much shorter interval (200 msec). 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 msec. The results were consistent with those of the present experiment; that is, the participants were slower to respond when an abrupt onset appeared in the display (mean RT = 500 msec) than when an abrupt onset did not appear (mean RT = 479 msec) [$t(7) = 3.01$, $p < .05$].

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).

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