Psychonomic Bulletin & Review
2002, 9 (1), 80-85

BRIEF REPORTS

Inhibition of return in static and dynamic displays

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Inhibition of return (IOR) causes people to be slower to return their attention to a recently attended object (object-based IOR) or location (location-based IOR). In attempts to separately measure the two components, moving stimuli have been used that permit the dissociation of the attended object from its location when it was attended. The implicit assumption has been that both object- and location-based components of IOR will operate whenever the cued object and cued location are identical. We show here that although this assumption may be true in a static display, it appears to be unwarranted when moving stimuli are involved: Very little IOR is observed when a cued object moves away from, and then subsequently returns to, its initial location. Thus, the processes that underlie IOR operate very differently in static versus dynamic scenes.

When a person's attention is reflexively drawn to a location in the periphery by a flash of light, stimuli presented there enjoy a processing advantage for a short period of time. However, if as little as 300 msec elapses, stimuli presented at the cued location may be at a disadvantage. The latter inhibitory effect has been called *inhibition of return* (IOR) because people are presumed to be inhibited in returning their attention to the recently attended (cued) location (Posner & Cohen, 1984).[1] IOR is thought to facilitate the sampling of fresh sources of input.[2]

With a static stimulus display, inhibition to return attention to a previously cued object could be due to inhibition that is associated with the object itself or to inhibition that is associated with the location that the object occupies, or both. Indeed, IOR appears to operate in both object-based and location-based reference frames. In particular, when a cued object moves away from the originally cued location, people are slower to detect stimuli in the cued object at its new location, revealing object-based IOR (Abrams & Dobkin, 1994; Tipper, Driver, & Weaver, 1991; Tipper, Weaver, Jerreat, & Burak, 1994; Weaver, Lupíañez, & Watson, 1998). People are also slower to detect stimuli presented at the earlier location of the object (i.e., the location that the object had occupied at the time of cuing), indicating the presence of location-based IOR (Tipper et al., 1994). Importantly, the magnitude of the object-based component and of the location-based component when measured individually are typically smaller than the magnitude of IOR observed when static displays are used. The reason for this presumably is that both object-based and location-based components affect a cued object in a static display, so there is more total IOR available compared with when the individual components are measured separately.

In the present paper, we examined the assumption just noted: The object- and location-based components of IOR measured individually with dynamic displays are both operable in a static situation. Indeed, without evidence to the contrary, this is a reasonable assumption. However, recent findings of McCrae and Abrams (2001) have led us to reexamine it. McCrae and Abrams studied IOR in older adults with the use of both static and dynamic displays. The older adults revealed a robust static IOR effect (58 msec), presumed to reflect the combined operation of object- and location-based components. Indeed, they also revealed 23 msec of location-based IOR. However, older adults were actually 14 msec faster to detect stimuli in a cued object than in an uncued object. Thus, they did not have any object-based IOR; instead, they demonstrated an object-based facilitatory effect. Clearly, in older adults, the individual components of IOR when measured with dynamic stimuli, do not simply combine in situations in which the stimuli remain fixed.

Our goal in the present study was to more carefully examine the presumed combinatorial properties of object- and location-based IOR in young adults. Indeed, it may simply be the case that the two components combine for younger but not for older adults. However, it is also possible that it is a coincidence that the components seem to add together in young adults. To explore this issue, we developed a new approach that allowed us to measure the combined effects of object- and location-based IOR in both static and dynamic settings.

This research was supported by Grant MH45145 from the National Institutes of Health and Grant BCS-0079594 from the National Science Foundation. We thank Patricia Reuter-Lorenz and two anonymous reviewers for their comments on an earlier version of the paper. C. S. McCrae is now at the University of Florida, Gainesville. Correspondence should be addressed to R. A. Abrams, Department of Psychology, Washington University, St. Louis, MO 63130-4899 (e-mail: rabrams@artsci.wustl.edu).

EXPERIMENT 1

The present experiment included two conditions in which the cued object occupied the same location at the time of cuing and target presentation. The first condition was a traditional static paradigm in which the cued object remained fixed throughout the trial. In the second condition, an object was cued, moved away from and then moved back to its original location before target presentation. In both situations, the inhibited object was always in the originally cued location at the time of target presentation. Hence, both conditions might be expected to reveal substantial IOR if the object- and location-based components can be presumed to both be operating. However, if the mechanisms involved in producing IOR to dynamic stimuli differ from those that underlie IOR in a static situation, as suggested by the results of McCrae and Abrams (2001) discussed above, the magnitude of IOR in the two conditions might not be comparable. Such a finding would force a reevaluation of current models of IOR.

Method

Subjects. Twelve undergraduates were recruited from the Washington University community. They were all naive with respect to the present experimental hypothesis. They were paid $6.00 each for their participation. One potential subject was replaced due to an excessive error rate (16%).

Apparatus and Procedure. The subjects were seated in front of a computer monitor in a dimly lit room. Their heads were steadied with a chinrest. There were two types of trials: *dynamic* trials and *static* trials. The sequence of events on a dynamic trial is illustrated in Figure 1. Each trial began with a fixation display that contained a central dot flanked by two 1° boxes. The boxes appeared at the upper left and lower right corners or the lower left and upper right corners of an imaginary 14° square centered on the fixation point. The initial display was presented for 800 msec after which the central dot was brightened and slightly enlarged for 100 msec before it returned to its initial state. Following a 300-msec delay, one of the boxes was cued, which entailed the brightening and filling in of the box for 50 msec. This was followed by a 117-msec delay. On movement trials, the boxes then moved either vertically or horizontally smoothly across the screen to the previously unoccupied corners of the imaginary 14° square and then back to their original positions. The motion was accomplished by displaying the boxes at each of 20 equally spaced positions along the movement path, each for 16.6 msec (total movement time for the 19 displacements = 317 msec). One hundred thirty-three milliseconds after movement began, the central dot was brightened and enlarged slightly for 50 msec. After movement had ceased, a 50-msec, 400-Hz warning beep was sounded, followed by a 100-msec delay. On noncatch trials, a 0.5° circular target was then presented in one of the two boxes. The resulting stimulus onset asynchrony (SOA) was 633.33 msec, which is very similar to that used in other experiments investigating IOR in both static and moving paradigms (e.g., Tipper et al., 1994; Weaver et al., 1998). On catch trials, no target was presented. The subjects were instructed to press the space bar on the keyboard as quickly as possible when the target appeared and to refrain from responding on catch trials. Trial presentation on static trials was identical to that on dynamic trials with one exception: Instead of moving, the boxes remained fixed at their original locations throughout the trial.

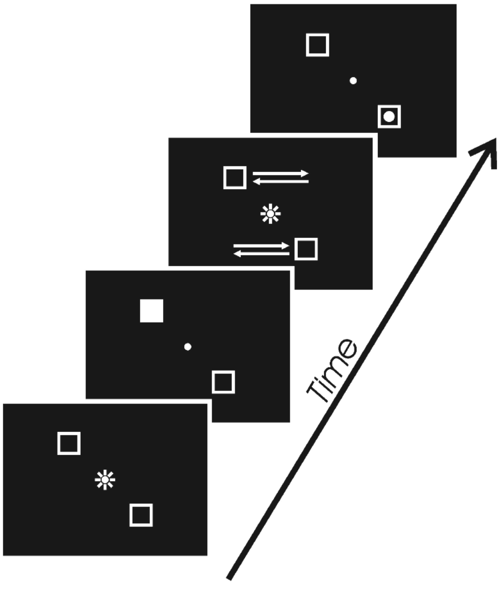

Figure 1. Sequence of events on a dynamic trial in Experiment 1.

If a subject responded on a catch trial or responded in less than 100 msec after target onset (an anticipatory response), a brief tone followed by the message "Too early" was presented. Conversely, if a subject failed to respond within 1,200 msec on a noncatch trial, a tone and a "Too slow" message were presented. After each block, the subjects were informed of their mean reaction time (RT) and number of errors.

Design. After 60 practice trials, the subjects served in 420 experimental trials, 140 of which were in the *dynamic–horizontal* condition, 140 of which were in the *dynamic–vertical* condition, and 140 that were in the *static* condition. Twenty percent of the trials in each condition were catch trials in which no target was presented. Trial presentation was balanced so that cue and target were equally likely to appear in the same box (cued trials) or in different boxes (uncued trials), and each was equally likely to appear in either of the two boxes. Furthermore, the boxes were equally likely to start in the bottom right and top left corners of the display or in the bottom left and top right corners of the display. For each potential set of starting positions, the boxes were equally likely to move horizontally or vertically across the screen in the dynamic condition. The trial types were randomly mixed. At intervals of 60 trials, the subjects were given the opportunity to take a break.

Results and Discussion

Trials on which the subjects responded in less than 100 msec after the target (an anticipatory response) or failed to respond within 1,200 msec after the target were coded as errors and were excluded from further analysis. A response on a catch trial was also coded as an error.

Mean RTs from each condition are shown in the top panel of Figure 2. The data were submitted to a 2 (cued vs. uncued) × 3 (dynamic–horizontal movement vs. dynamic–vertical movement vs. static) analysis of variance (ANOVA). There was a main effect of cuing, with the subjects being slower to detect cued targets than uncued ones [$F(1,11) = 7.62$, $p < .05$]. This is the typical IOR effect. There was also a main effect of display type, with the subjects responding faster overall in the dynamic conditions[3] than the static condition [$F(2,22) = 20.63$, $p < .001$]. Most relevant to the present investigation, a significant interaction between cuing and display type was seen. We ob-

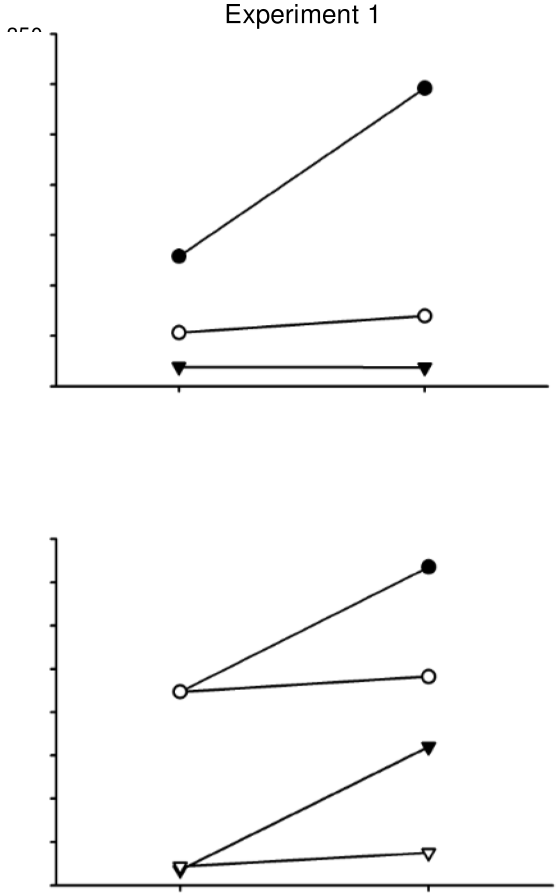

Figure 2. Mean reaction times from Experiment 1 (top panel) and Experiment 2 (bottom panel) as a function of condition.

served 34 msec of IOR in the static condition, but only 3 and 0 msec in the dynamic–horizontal and dynamic–vertical conditions [$F(2,22) = 12.67$, $p < .001$], respectively. These results suggest that the components of IOR as measured with dynamic stimuli may differ from what is observed with static stimuli.[4] Additional implications of these findings are discussed in the General Discussion section.

Overall, the mean error rate was very low (3.3%). Error data from noncatch trials were submitted to a 2 (cued vs. uncued) × 3 (dynamic–horizontal movement vs. dynamic–vertical movement vs. static) ANOVA. There was a main effect for display type, with the subjects making slightly more errors in the static condition ($M = 1.4\%$) than in the dynamic–vertical ($M = 0.7\%$) or dynamic–horizontal ($M = 0.2\%$) conditions [$F(2,22) = 4.01$, $p < .05$]. Neither a significant main effect for cuing nor a significant interaction between cuing and display type was seen in the noncatch trial data. Error data from the catch trials were submitted to a one-way (dynamic–horizontal movement vs. dynamic–vertical movement vs. static) ANOVA. The pattern of results obtained was the reverse of what was seen with the noncatch trial errors, with more errors occurring in the dynamic–vertical ($M = 21.1\%$ of the catch trials) and dynamic–horizontal ($M = 13.1\%$) conditions than in the static condition ($M = 6.3\%$) [$F(2,22) = 6.56$, $p < .01$]. The false alarms on catch trials reflect the subjects' bias to expect a target since the catch trials were relatively infrequent (20% of the total trials).

At this point, it is also reasonable to consider whether the stimuli used in the present experiment were indeed capable themselves of invoking separate object-based and location-based IOR effects. We conducted two control experiments to confirm that (1) the subjects could actually track, and be inhibited in returning attention to, the moving objects used here,[5] and (2) the stimulus and timing parameters were sufficient to also elicit location-based IOR. In both control experiments, the objects moved away from the original location but never returned. In the first experiment, the targets were always presented in either the cued or the uncued object. In that case, with the use of the same objects moving at the same speed as in Experiment 1, we were able to demonstrate an object-based IOR effect [$M = 7$ msec; $N = 12$; $t(11) = 2.21$, $p < .05$]. Thus, the subjects clearly were able to track the object motion. In the second experiment, the targets were always presented at either the cued location or in the opposite corner of the display. In this case, we found a location-based IOR effect [$M = 7$ msec; $N = 8$; $t(7) = 5.34$, $p < .005$]. Thus, the experimental parameters were sufficient to elicit both object- and location-based IOR separately.

EXPERIMENT 2

The present experiment was designed to extend the findings of Experiment 1, as well as to control for alternative explanations of the observations. In particular, one possible explanation for the failure to observe IOR in the dynamic conditions of the previous experiment involves a possible floor effect: Latencies in the dynamic conditions were relatively short, perhaps affording little opportunity to observe IOR. Latencies in the static condition, however, were slower, and IOR was revealed there. Why might latencies be shorter in dynamic as opposed to static conditions? We believe that the movement of the boxes in the dynamic conditions (and, in particular, their absolute location on the display) afforded the subjects a cue that allowed them to accurately anticipate the moment at which the target would be presented. Consistent with this, the subjects were faster and more likely to produce false alarms on the dynamic trials. Such a cue was not available in the static condition—hence, the subjects were slower there. Bolstering this possibility is the fact that we used only one cue–target interval in Experiment 1, further rendering target anticipation more likely.

A second concern regarding Experiment 1 involves the behavior of the subjects' eyes during the experiment. As has been shown in the past, eye movements can cause (Rafal, Calabresi, Brennan, & Sciolto, 1989) or be affected by (Abrams & Dobkin, 1994) IOR. Thus it would seem possible that different patterns of eye movements on dynamic and static trials could lead to differing amounts of IOR in those conditions. Despite the fact that we admonished the subjects to remain fixated at the center of the display throughout all conditions, we had no way to monitor compliance with that request.

In Experiment 2, we addressed each of the concerns noted above. In order to reduce temporal predictability, we used two randomly mixed cue–target intervals for both the static and the dynamic conditions. To address compliance with the fixation request, we monitored the subjects' eye position throughout the experiment.

Method

Subjects. Ten undergraduates were recruited from the Washington University community. They were all naive with respect to the present experimental hypothesis. They were given course credit for their participation.

Apparatus and Procedure. The apparatus and procedure were identical to that of Experiment 1 with a few exceptions: Only two display conditions were employed—static and dynamic–horizontal. Two different SOAs were used, 633 and 933 msec. Trial presentation on the trials with a 633-msec SOA was identical to that in Experiment 1. For trials with the 933-msec SOA, the timing of the cue and movement was identical to that in Experiment 1; however, following the conclusion of the movement, 450 msec passed before the target was presented (compared with 150 msec in the 633-msec SOA trials). Trial presentation on the static trials was again identical to that on dynamic trials, with the exception that the boxes remained fixed at their original locations throughout the trial.

An ISCAN RK426PC (Iscan, Cambridge, MA) was used to track eye position during the experiment. Immediately before each trial, the subject's eye position was sampled using the ISCAN monitor to ensure that he/she was fixated at the center of the display. If the subject failed to fixate correctly, trial presentation would not begin until the subject complied. Once fixation was confirmed, trial presentation proceeded as described above. Eye position was also sampled throughout the trial until a response was recorded. The resulting data samples were analyzed for eye movements as follows: To determine the onset of saccades, eye movement samples were filtered and differentiated to obtain a smooth record of velocity. A saccade was deemed to have occurred if the velocity exceeded 10°/sec for a period of 34 msec or longer. This is similar to the method that we have used previously (e.g., Abrams, Pratt, & Chasteen, 1998).

In addition to receiving feedback when an anticipatory response or no response was made, the subjects received a tone and an error message (viz., "Eye movement detected") if an eye movement was detected during a trial. Such trials were coded as errors and were excluded from further analysis.

Design. Following 32 practice trials, the subjects served in 288 experimental trials, 144 of which were in the dynamic condition, and 144 of which were in the static condition. For each condition, 72 trials had an SOA of 633 msec, and 72 trials had an SOA of 933 msec. Trial presentation was balanced so that cue and target were equally likely to appear in the same or different box, and each was equally likely to appear in either of the two boxes. The various trial types were randomly mixed and grouped into blocks of 32 trials each, allowing the subjects the opportunity to take breaks during the session.

Results and Discussion

Mean RTs in each condition are shown in the bottom panel of Figure 2. The data were submitted to a 2 (cued vs. uncued) × 2 (dynamic movement vs. static) × 2 (633-msec SOA vs. 933-msec SOA) ANOVA. As in Experiment 1, there was a main effect of cuing: The subjects were slower to detect targets appearing in cued objects than in uncued ones [$F(1,9) = 8.261$, $p < .05$]. There was also a main effect for SOA, with subjects being faster in the 933-msec SOA condition than in the 633-msec SOA condition [$F(1,9) = 63.69$, $p < .001$], perhaps reflecting a warning or expectancy effect. In contrast to Experiment 1, there was no main effect of display type [$F(1,9) = 3.45$, n.s.]. Most importantly, the effects of cuing and display type interacted: At both the 633-msec SOA and the 933-msec SOA, we observed more IOR in the static condition (29 msec in both cases) than in the dynamic condition (3 and 4 msec, respectively) [$F(1,9) = 13.04$, $p < .01$]. No other interactions approached significance.

Overall, the mean error rate was very low (6.1%). Error data were submitted to a 2 (cued vs. uncued) × 2 (dynamic movement vs. static) × 2 (633-msec SOA vs. 933-msec SOA) ANOVA. The only effect that approached significance was a main effect for SOA, with subjects making fewer errors in the 633-msec SOA condition ($M = 4.7\%$) than in the 933-msec SOA condition ($M = 7.5\%$) [$F(1,9) = 4.83$, $p > .05$]. Although the difference is not statistically significant, it may explain, in part, the main effect of SOA seen in the RT data (the subjects made more errors, yet responded faster in the longer SOA condition—a speed–accuracy tradeoff). No other factors affected the errors [$Fs(1,9) < 1$].

As noted earlier, one potential concern was in regard to the differential effects that eye movements may have had on our RT findings. To address this, we analyzed the eye movement errors independently of other types of errors to investigate any possible systematic relationship between the number of eye movements detected and the experimental condition. This analysis, a 2 × 2 × 2 ANOVA, revealed only one significant effect, an interaction between SOA and cuing [$F(1,9) = 5.41$, $p < .05$]. At the 633-msec SOA, the subjects were more likely to erroneously make an eye movement on an invalid trial ($M = 4.3\%$) than on a valid trial ($M = 3.5\%$). The opposite was true at the 933-msec SOA—an eye movement was more likely to occur on valid ($M = 5.1\%$) as opposed to invalid trials ($M = 4.2\%$). Most importantly, an interaction between cuing and display type was *not* observed [$F(1,9) = 0.06$]. This suggests that the differing amounts of IOR observed for each display type were not directly related to the presence of overt eye movements. No other factors affected the occurrence of eye movements [$Fs(1,9) < 1.28$, $p > .27$].

Also of note, one may wonder whether the abrupt change in the direction of movement of the boxes in our experiments attracted attention, perhaps offsetting any effects of IOR in the dynamic conditions. In some unpublished experiments, we have included conditions in which the direction of box movement changed gradually, not abruptly. In that case, we found results very similar to those reported here. Furthermore, if the reversal of the boxes had attracted attention, the resulting facilitation might be expected to be reduced, by decay more in the 933-msec SOA condition of the present experiment than in the 633-msec SOA condition. However, no IOR was observed in either of these conditions, further arguing against the possibility that the reversal of movement attracted attention.

The present results replicate and extend the findings from Experiment 1. As was true there, the amount of IOR was dramatically reduced when the cued object moved away from and then returned to its initial location, despite the fact that both object-based and location-based components of IOR might be thought to be operating. The present experiment also demonstrates that the phenomenon is not affected by a reduction in temporal uncertainty and hence in the ability to predict when the target will be presented. Additionally, the two SOAs yielded latencies that differed by 41 msec, yet this difference had no effect on the magnitude of the static or dynamic IOR. Finally, we can be certain that the results were not caused by some difference in the eye movements that the subjects made in the different conditions: No eye movements were made during the present experiment.

GENERAL DISCUSSION

In the present experiments, very little IOR occurred when subjects detected a target in a cued object that had moved away from, but then subsequently returned to, its initial location. This result is inconsistent with the commonly held assumption that both object-based and location-based IOR will operate whenever attention must return to a cued object at its originally cued location. Instead, we conclude that the processes involved in producing IOR to moving objects are different from the processes involved in IOR for static stimuli. One consequence of this difference is that it might not be possible to use dynamic displays to separately assess the individual components that are thought to comprise static IOR. This is because the processes involved in producing IOR in dynamic displays might be different from those for static displays.

Recent evidence suggests that separate object- and location-based components of IOR might operate in static displays. Jordan and Tipper (1998) showed that subjects were slower to return attention to a cued location if the location was contained in a perceptual object, compared with a location that was not part of a perceptual object. The object appeared to provide an additional frame of reference within which IOR could operate. What is not known, however, is whether the static object-based component that Jordan and Tipper identified is the same as the object-based IOR that moves with an object in a dynamic display. Whatever the answer, it seems clear that some additional process is involved when stimuli move. This is because we found almost a complete obliteration of the IOR when the object returned to its initial location.

The observed differences in IOR when measured in static versus dynamic displays may reflect the nature of the different neural substrates underlying the phenomenon in each of these situations. Several sources of evidence implicate the superior colliculus (SC), a subcortical region, in IOR (Posner, Rafal, Choate, & Vaughan, 1985; Rafal et al., 1989; Sapir, Soroker, Berger, & Henik, 1999; Valenza, Simion, & Umiltà, 1994). However, those results were obtained with static stimuli. Because the SC does not signal direction of movement (Schiller, 1972), it seems unlikely that it is capable of producing object-based IOR. Instead, object-based IOR is thought to require cortical processing, and evidence consistent with that possibility has been reported (Tipper et al., 1997).

We are not the first to suggest that the "rules" of IOR might change when moving stimuli are introduced to an otherwise static display. Tipper et al. (1994) reported an experiment in which the display contained two static objects and two moving objects. In the relevant condition, the static objects were cued and probed, whereas the moving objects could be ignored. Tipper et al. (1994) found that the IOR observed in that condition was significantly less than in similar static IOR experiments, in which no moving objects were present. They concluded that the presence of motion might invoke an object-based representation for the IOR. In a completely static display, a simpler location-based (or environment-based) reference frame would suffice.

To accommodate the present findings, we suggest a similar explanation. In particular, when moving stimuli are present, we believe that a cortical object-based system is invoked. Furthermore, when a moving object returns to a previously cued location, we believe that the object-based system can suppress the subcortical location-based system in a top–down manner. The only inhibition that would be available in such a situation would be that which is attributable to the object-based component, which sometimes is very small. (In Experiment 1, that was 0 and 3 msec of IOR in the two dynamic conditions; in Experiment 2, it was 3 and 4 msec at the two different SOAs.) Regardless of the nature of the mechanisms involved, it seems clear that motion produces a change in the processes that generate IOR.

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NOTES

1. In a typical experiment (see, e.g., Posner & Cohen, 1984), a subject will view a display containing two peripheral boxes to the left and right of a central fixation marker. Attention is first attracted to a box by flickering it (the cue) and then (optionally) is drawn away from the box by flickering the central fixation marker. A short time later, a target may be presented in either the cued or the uncued box for subjects to detect or discriminate. Inhibition of return is revealed when subjects are slower to perform the detection or discrimination for targets in the cued box.

2. Note that there is presently some uncertainty regarding the extent to which IOR involves inhibited perception or attention as opposed to inhibited responding, with evidence consistent with both possibilities (see Abrams & Dobkin, 1994; Kingstone & Pratt, 1999; Pratt, Kingstone, & Khoe, 1997; Taylor & Klein, 1998). The resolution of this issue one way or another does not bear on the present study. However, given the differences between static and dynamic stimuli that we will describe here, continued investigation of this issue might be worthwhile.

3. A planned *t* test revealed that, overall, the dynamic–vertical movement condition did not differ significantly from the dynamic–horizontal condition [$t(11) = 2.04, p > .05$].

4. It is worth noting that we have also replicated this result with a group of 12 subjects who experienced the static condition and the dynamic–horizontal condition. The interaction between cuing (cued/uncued) and display type (static/dynamic) was significant [$F(1,11) = 7.68, p < .05$], revealing 37 msec of IOR in the static condition, but only 13 msec in the dynamic–horizontal condition.

5. We report the experiment here, although one might argue that the results are not directly relevant to the present issue. In particular, if the subjects had revealed no object-based IOR in the control experiment, one might be tempted to conclude that the motion of the object was not sufficient to permit the "already attended" tag to remain attached as it moved. Such a case might be expected to be very similar to the situation in which an object does not move at all, and it might be expected to yield a large amount of IOR, contrary to our results.

(Manuscript received September 28, 1999;
revision accepted for publication April 12, 2001.)