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Inhibition of Return to an Occluded Object Depends on Expectation

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Inhibition of return (IOR) is indexed by slower reaction times to targets presented at previously attended locations or objects. If a moving object is occluded, some studies find IOR, others do not. Four experiments examined whether this inconsistency hinges on the observer's expectation as to whether the object continues to exist at the end of its motion sequence. Results showed that observer expectation is a powerful determining factor: IOR occurs only if the observer expects the object to continue to exist. In contrast, if the object is not occluded, IOR occurs only if the object remains on view immediately before the target is presented. It was concluded that 2 factors, object continuity and observer expectation, mediate both location- and object-based IOR.

Keywords: inhibition of return, expectancy, attention, occlusion, object continuity

People constantly scan the visual environment for information about objects: where they are, where they are moving to, and which are new in the scene. Considering the vast amount of information entering the visual system at any given moment, some selectivity must be exercised in order to focus on the most relevant objects. One of the guiding principles for such selectivity is the phenomenon of *inhibition of return* (IOR), which is typically indexed by slower reaction times (RTs) to stimuli that appear at previously attended locations. It has been argued that IOR serves to guide visual search away from previously attended locations so as to maximize the amount of new information entering the system (Maylor, 1985; Posner & Cohen, 1984).

In this case, the functional significance of IOR would be to prevent the perseverative examination of previously attended locations (Klein, 1988). In order to accomplish this goal, IOR must function within an environment-based coordinate system, and this indeed appears to be the case (Posner & Cohen, 1984). Furthermore, if IOR is to be useful in the real world, it should be in evidence not only with reference to environmental locations but also with reference to objects, both static and in motion. This has been confirmed for static objects by Jordan and Tipper (1998) and for moving objects by Tipper, Weaver, Jerreat, and Burak (1994).

In a seminal study, Tipper, Driver, and Weaver (1991) displayed three squares along a horizontal axis. Observers fixated on the central square while one of the outer squares was cued by a brief flash. The two outer squares then moved in a clockwise fashion some distance along an imaginary circle. RTs were slowed both to targets that were presented at the location where the cued square first appeared (location- or environment-based IOR) and to the cued square itself at its new location (object-based IOR). From this finding, Tipper et al. concluded that the mechanisms involved in producing IOR can access both object-based and environment-based representations of the visual scene (see also Ro & Rafal, 1999; Tipper, Jordan, & Weaver, 1999; Tipper et al., 1994).

One striking characteristic of moving objects is that they frequently become occluded by other objects. Hence, not only must IOR act on moving objects if it is to be useful in the real world, but it must also accommodate brief occlusions of these objects. Indirect evidence suggests that this may well be the case. For instance, when a small portion of a relatively large object is cued, IOR spreads across the entire object even if part of the object is occluded (Jordan & Tipper, 1999; Leek, Reppa, & Tipper, 2003; Reppa & Leek, 2003).

Initial research by Tipper et al. (1994), in which a moving object was cued after it disappeared behind an occluder, failed to yield IOR, leading to the conclusion that a *visible* object is necessary for IOR to occur. Recent research, however, has reexamined this issue and found convincing evidence to the contrary. In an experiment that closely mirrored that of Tipper et al., Yi, Kim, and Chun (2003) found IOR to moving objects that were occluded at some point in their trajectory. Thus, it appears that object-based IOR may occur in response to occluded objects, at least under certain conditions.

The present need is to define the conditions under which IOR to occluded objects does (Yi et al., 2003) or does not (Tipper et al., 1994) occur. The object-permanence literature provides some direction in this respect. It is known that by 9 months of age, infants show surprise if an object (e.g., a ball) that has rolled behind an occluding surface (e.g., a box) is not present when the box is removed (Leslie, Xu, Tremoulet, & Scholl, 1998; Spelke, Kestenbaum, & Simon, 1995). If, however, they have reason to believe that the ball may disappear when it rolls behind the box (e.g., there is a large hole in the floor), then the infants are no longer surprised that the object is not present when the occluding surface is re-

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moved. In fact, they show surprise if the object *does* remain present (Spelke et al., 1995). This finding suggests that observer expectation may be critical in determining whether the representation of an occluded object is maintained, and consequently in determining whether IOR is maintained to an occluded object.

In the present work, we consider whether observer expectation is a factor in determining whether IOR is found to an occluded object. In Experiment 1, we established that observer expectation is indeed an important determinant of IOR. In Experiment 2, we asked whether IOR to an occluded object can be obtained when awareness of the occluder itself is based not on physical evidence but on a memory representation. Finally, Experiment 3 was designed to determine whether IOR would be reduced if the observer's expectation that the object continued to exist behind the occluder is disconfirmed.

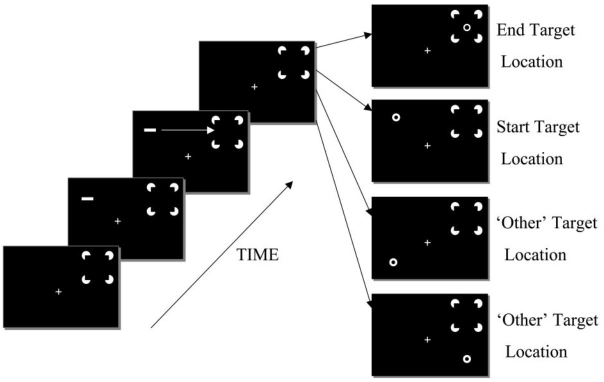

Figure 1. Sequence of events on a typical trial in Experiment 1. All trials began with the presentation of the fixation cross and the occluder, which could appear in any of the four quadrants on any given trial. After a random stimulus onset asynchrony of 1,000–2,500 ms, an object (a short line) appeared, remained stationary for approximately 300 ms, and then moved horizontally across the screen in 180 ms. After the motion sequence was complete, there was an interval of approximately 400 ms before the target (a small ring) appeared. Illustrated here is an occluder trial, namely, a trial in which the object disappeared behind the occluder at the end of the motion path. In a context trial, the object moved along the lower half of the screen. The four possible target locations are illustrated in the four panels on the right side of the figure.

Experiment 1

Experiment 1 was designed to determine whether the incidence of IOR is predicated on observer expectation. To this end, we influenced the observer's expectations about the behavior of a moving object that disappeared behind an occluder by manipulating the observer's experience of the same object when it was not occluded. If observer expectation is a determinant of IOR, then IOR should be in evidence only when the observer expects that the object continues to exist at the end of its motion sequence.

Method

Observers. Forty-two undergraduate students, ages 18–25 years from the University of British Columbia (Vancouver, British Columbia, Canada), participated in the experiment for course credit. All were right-handed, had normal or corrected-to-normal vision, and were naïve as to the purpose of the experiment. They were randomly allocated to two equal groups.

Stimuli. All stimuli were displayed on a computer monitor set at a resolution of 1024 × 768 pixels and were refreshed at a rate of 60 Hz. Stimuli appeared light gray (26 cd/m^2) against a black background (2.3 cd/m^2). Each trial began with the presentation of two stimuli: a fixation cross and an occluder. The fixation cross, which subtended 0.5° × 0.5° of visual angle, was displayed at the center of the screen and remained present throughout each trial. The occluder, which was formed by four "Pacmen" figures (three-quarter disks of 1.5° diameter) rotated inward to form a Kanizsa square, subtended 3.8° × 3.8° of visual angle and was presented in one of the four quadrants of the screen, centered 8.2° from fixation (see Figure 1). A moving object consisting of a small line, which subtended 0.8° × 0.1°, was presented at the center of one of the four quadrants and was stationary for 304 ms before beginning to move. Motion was produced by presenting the object 0.8° further along its horizontal motion path for 15 frames of 12 ms each. The total length of the motion path was 12°, with object motion lasting for approximately 180 ms. On some trials, the object appeared to slide behind the occluder, and it did so in stages so that it disappeared realistically. After the object stopped moving, a target consisting of a small gray ring (0.5° diameter) was presented centered in one of the four quadrants (including on top of the occluder). Observers responded to the onset of the target by pressing the space bar; RTs were recorded with millisecond resolution.

Design. As noted above, one quadrant of the screen contained a Kanizsa square that acted as an occluder for an object (a short line) that moved along a horizontal path across the screen. On a given proportion of trials, the motion path ended at the edge of the occluder, with the object appearing to slide behind the occluding surface. Our main objective was to manipulate the observer's expectation as to whether the object continued to exist behind the occluder or whether it ceased to exist at the end of the motion path. To this end, we used two types of trials: *occluder* trials and *context* trials. These can best be explained by example and are illustrated in Figure 2.

Imagine a trial on which the occluder is located in the upper-right quadrant of the screen. On occluder trials, the object's motion path would start in the upper-left quadrant and end when the object appeared to slide behind the occluder. On context trials, in contrast, the object would move between the lower-left and lower-right quadrants and, therefore, would end on a blank part of the screen. There were two types of context trials aimed at inducing different expectations regarding the fate of the object at the end of its motion path. In one type of context trial (*present* trials), the object remained on view for 400 ms at the end of its motion path before disappearing. In the other type of context trial (*absent* trials), the object disappeared immediately when it stopped moving.

The expectation regarding the fate of the object on occluder trials (i.e., when it disappeared behind the occluder) depended on the type of associated context trial. For one group of observers (the *present* group), occluder trials were mixed randomly with present-context trials, establishing the expectation that, on occluder trials, the object would continue to exist for some time (i.e., for 400 ms) behind the occluding surface. This group never experienced absent-context trials. For the other group of observers (the *absent* group), occluder trials were mixed randomly with absent-context trials, establishing the expectation that, on occluder trials, the object would disappear at the end of the motion path and, therefore, would not continue to exist behind the occluder. This group never experienced present-context trials. To be clear about this, the only relevant difference between the two groups was that on context trials, the object remained visible for 400 ms after the end of the motion sequence in the present group but disappeared immediately in the absent group.

To assess the presence of IOR, we presented a target (a small ring) in one of the four quadrants 400 ms after the object stopped moving. Observers were required to press the space bar as quickly as possible on seeing the target. Even though the target was presented equally often in each quad-

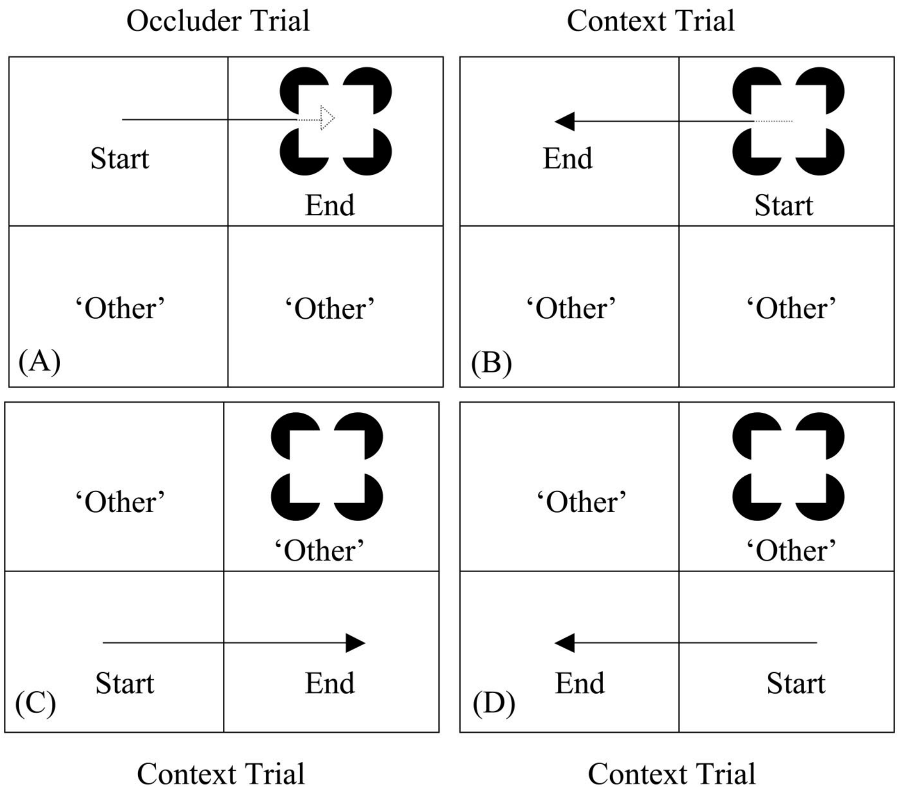

Figure 2. Schematic diagram distinguishing between occluder and context trials. The occluder was presented equally often in each of the four quadrants (80 out of 320 trials). Illustrated here are only trials in which the occluder was presented in the upper-right quadrant. A: an occluder trial. B, C, and D: context trials. Twenty-five percent of all trials (80 out of 320) were occluder trials whose distinguishing characteristic was that the object appeared to slide behind the occluder. Seventy-five percent of all trials (240 out of 320) were context trials whose distinguishing characteristic was that, unlike occluder trials, the object was visible at the end of the motion path. Also illustrated in this figure are the screen locations at which the target was presented, relative to the object's motion path. Start trials were trials in which the target was presented at the starting point of the object's motion path. End trials were trials in which the target was presented at the end point of the object's motion path. Finally, "other" trials were trials in which the target was presented in one of the two quadrants other than those in which the object had appeared during its motion path.

rant, its location can be classified in one of three categories as it relates to the moving object: *start*, *end*, and *other*. In the start category, the target was presented at the starting point of the object's motion path. In the end category, the target was presented at the end point of the object's motion path. Finally, in the "other" category, the target was presented in one of the two quadrants other than those in which the object had appeared during its motion path.

Procedure. Observers sat at a distance of approximately 60 cm from the screen and completed 20 practice trials before beginning the experiment proper. Observers were instructed to maintain fixation on the central fixation cross throughout each trial. Each trial began with the presentation of the fixation cross and the occluder. The quadrant in which the occluder appeared was blocked over trials. The order of occluder location was counterbalanced across observers. After a random stimulus onset asynchrony (SOA) of 1,000–2,500 ms, an object (a short horizontal line) was presented in the center of one of the four quadrants, remained stationary for 304 ms, and then moved horizontally across the screen. The initial quadrant in which the object appeared was determined randomly, with the restriction that the object started in each of the four quadrants an equal number of times within each block of trials. Once the object's initial location had been selected, there was only one possible motion path. Given that there were four possible motion paths and four possible target locations, the experiment consisted of 16 combinations of object motion path and target location, each of which occurred with equal frequency in each block. In the 25% of the trials in which the object's motion path began in the same quadrant as the occluder, the object was not presented on top of the occluder for the initial 304-ms interval, as this might have interfered with the establishment of an expectation that the object disappeared behind the occluder on the relevant trials. Rather, consistent with that expectation, the object appeared to slide out from underneath the occluder. The timing of these trials was the same as the timing in the remaining 75% of the trials, except that instead of being on view for the initial 304 ms, the object was occluded for the same interval. In every other respect, these trials were identical to all other trials and were treated in the same way. In addition, a random 20% of the trials were *early-target* trials in which the target was presented only 12 ms instead of 400 ms after the object stopped moving. This was done for two reasons: first, to prevent the establishment of rhythmic responding and, second, as an exploratory means of determining the locus of attention at the time of motion termination. The experiment proper consisted of a total of 420 trials, including 20 practice trials. The remaining trials comprised 20 repetitions of each of the 16 types of trials and 80 early-target trials.

Results and Discussion

The results of the present study can be related to the results of conventional studies of IOR in which visual cues are used to direct attention to an object or location. In conventional studies, IOR is indexed by RT differences between trials in which the target appears at a previously cued location (cued trials) and trials in which the target appears at an uncued location (uncued trials). In the present study, a cue was not used; instead, we used a single object, which drew attention to itself naturally by means of its abrupt onset and its motion. Essentially, the object itself served as a cue. From this perspective, conventional cued trials corresponded to trials in which the target was presented at the end or start locations, whereas conventional uncued trials corresponded to trials in which the target was presented at the "other" locations. More specifically, trials in which the target appeared at the end location index what is conventionally referred to as *object-based* IOR. Trials in which the target was presented at the start location, however, correspond to what is conventionally called *location-* or *environment-based* IOR. Finally, conventional uncued trials corresponded to trials in which the target was presented at a location other than that occupied by the object at any point in its motion path.

It needs to be emphasized that the correspondence between the present paradigm and the conventional cue–target paradigm cannot be regarded as perfect. The closest parallel to the present study is the paradigm pioneered by Tipper et al. (1991), in which two objects are presented on opposite sides of fixation, with one object being cued in order to draw attention to it. Beyond this point, however, the present paradigm differs from that of Tipper et al. in that, after the presentation of the cue, Tipper et al.'s displays were balanced, with stimuli on opposite sides of fixation, whereas in the present paradigm, there was only one moving object.

Trials in which the observers responded before the onset of the target (anticipation errors) were excluded from the analysis. This resulted in the elimination of less than 1% of the trials. The results are illustrated in Figure 3. Median RTs were analyzed in a 2 × 2 × 3 analysis of variance (ANOVA), with one between-subjects and two within-subject variables.[1] The between-subjects variable referred to whether the object continued to exist (either in full view or behind the occluder) at the end of the motion sequence. We refer to this variable as *object continuity*: present or absent. One within-subject variable was trial type: occluder or context. The other was target location with respect to the object: start, end, or other. The analysis revealed significant effects of target location, $F(2, 80) = 25.12$, $p < .001$, and object continuity, $F(1, 40) = 4.50$, $p < .05$. The Target Location × Object Continuity interaction was also significant, $F(2, 80) = 10.92$, $p < .001$. No other effects were significant. Notably, there were no significant differences between the start and end target locations for the present group in either the context or the occluder conditions. This was confirmed in an additional 2 (trial type: context, occluder) × 2 (target location: start, end) within-subject ANOVA, which revealed no significant effect of trial type, $F(1, 20) = 0.95$, $p > .30$; target location, $F(1, 20) = 1.74$, $p > .20$; or Trial Type × Target Location interaction, $F(1, 20) = 0.473$, $p > .50$. This strongly suggests that the magnitude of IOR did not differ between the start and end locations in the present group. Analysis of the early-target trials, in which the target was presented only 12 ms instead of 400 ms after the object stopped moving, revealed no significant effects.[2]

The outcome of the analysis confirms the evidence in Figure 3 that RTs for the start and end target locations were slower than for the "other" target locations in the present condition but not in the absent condition. Given that IOR is indexed by slower RTs in the end (or start) target locations than in the "other" target location, these findings strongly suggest that the occurrence of IOR depends on the observer's expectation. Namely, IOR occurred in the present condition, in which observers expected the object to continue to exist after the end of the motion sequence but not in the

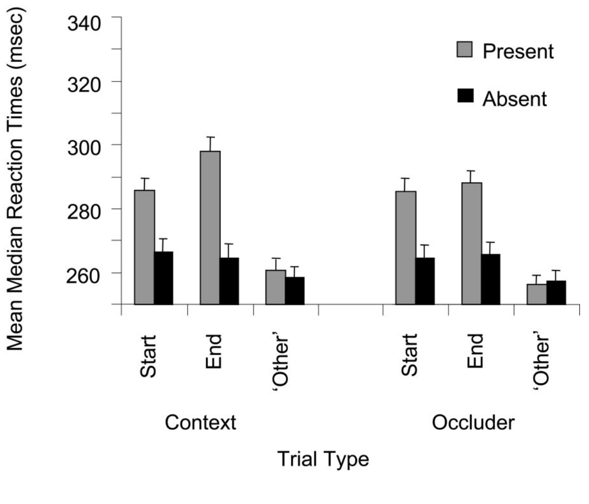

Figure 3. Mean median reaction times in Experiment 1. Error bars represent one standard error of the mean. msec = milliseconds.

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[1] Miller (1988) warned that median RT is a biased measure that is increasingly likely to overestimate the true mean as the size of the sample on which it is based becomes smaller. In the present work, the number of trials in the "other" target location was twice as large as that in either the start or the end locations. This raises the possibility that the median RTs in the start and end locations might have been overestimated in the present work. To check on this possibility, we compared median RTs with mean RTs in the start, end, and "other" target locations for the data in Figure 3. The median RTs were as follows (mean RTs in parentheses): start, 275.4 (276.2); end, 279.1 (278.2); and other, 258.0 (259.4) ms. It is clear that mean and median RTs differed by only about 1 ms in any given instance, demonstrating that Miller's warning does not apply to the present work.

[2] Median RTs for the early-target trials were analyzed in a 2 × 2 × 3 ANOVA, with one between-subjects and two within-subject variables. The between-subjects variable was object continuity: present or absent. One within-subject variable was trial type: occluder or context. The other was target location with respect to the object: start, end, or "other." The analysis revealed no significant main effects or interactions: target location, $F(2, 80) = 0.03$, $p > .9$; trial type, $F(1, 40) = 0.45$, $p > .5$; object continuity, $F(1, 40) = 0.23$, $p > .6$; p values for all interaction effects were all $> .50$. The overall mean for the early-target trials (collapsed across target location and trial type) was 304 ms. The corresponding mean for the trials in which the target was presented 400 ms after the end of the object's motion sequence (late-target trials) was 271 ms. The average difference between early- and late-target trials, therefore, was 33 ms. This difference is far smaller than the 400 ms difference that would be expected had the observers established a pattern of rhythmic responding.

absent condition, in which no such expectation had been established.

One possible concern with the above analysis is that the RTs at the start and end locations in the critical occluder condition might have been influenced differently by the fact that on end trials, the target was presented on the occluder's surface, whereas on start trials, it was presented on a blank part of the screen. It is possible that RTs at the end location might have been slowed down by local contour interactions because the target was presented on the occluder. Alternatively, the occluder may have served as a magnet that drew attention to its location, thus potentially affecting RTs to both start and end locations. Both these options are contradicted by the finding that RTs in the start location were approximately the same as in the end location (see occluder trials in Figure 3).

An unanticipated yet important outcome of the present study was that the effect of observer expectation was not confined to the occluded location but extended to the starting location as well. As seen in Figure 3, when the object was expected to continue to exist behind the occluder (present condition), IOR occurred not only at the occluded location ("other" vs. end locations), $t(20) = 4.08$, $p = .001$, but also at the start location ("other" vs. start locations), $t(20) = 3.73$, $p = .001$. In contrast, when the object was expected to cease to exist at the end of the motion sequence (absent condition), IOR failed to occur not only at the occluded location but also at the start location. The latter outcome is especially noteworthy: Given that in the absent condition the object was expected to cease to exist at the end of the motion sequence, it is perhaps not surprising that IOR did not occur at the end location. What is more surprising is that the absence of IOR extended back to the start location, where the display sequence was identical to that for the present group that exhibited sizable IOR. This strongly suggests that the effect of observer expectation is general and not confined to the occluded location. More specifically, the expectation established in the context trials with respect to the occluded location is automatically extended to the starting location. The establishment of a generalized attentional control setting in the present experiment parallels Klein's (2000) observation that in conventional (cue–target) IOR studies, the attentional control setting established for the target also applies to the cue.

An account of this pattern of results can be proposed in terms of *object files*, which are regarded as integrated representations of objects in working memory (Kahneman, Treisman, & Gibbs, 1992). An object file is said to contain all the relevant attributes and features of a given object, much as a file folder contains the relevant information on a given topic. Lupiáñez and colleagues have used the concept of object file to account for both the facilitatory and inhibitory effects evidenced in IOR (Lupiáñez & Milliken, 1999; Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001). The present finding that the effect of observer expectation generalizes beyond the occluder location can be explained in terms of object files on two assumptions. First, it must be assumed that the object file contains information concerning not only the object in its current location but also the history of that object, including its motion path. Second, it needs to be assumed that when the observer expects the object to continue to exist after the end of the motion sequence (present condition), the object file remains open after the object disappears behind the occluder. In this case, all the information about the object, including its motion path, remains available, and IOR ensues at both the end and the start locations. In contrast, when the object is expected to cease to exist at the end of the motion sequence (absent condition), the file is closed when the object disappears from the screen. In that case, information about the object can no longer be accessed directly, and IOR fails to occur at either location.

On the basis of this reasoning, location-based IOR and object-based IOR are determined jointly by the same factor, namely, observer expectation. When the expectation is for the object to continue to exist behind the occluder, the object file remains open, and IOR occurs. The important point here is that because the object file contains both start- and end-location information, the location- and object-based IOR are invariably linked. By the same token, when the expectation is for the object to cease to exist after it disappears from the screen, the object file is closed, and IOR does not occur at either location.

Given that observer expectation determines whether IOR occurs to an occluded object, it is of interest to ask whether the magnitude of IOR depends on whether the object is visible or occluded. It is plausible, for example, that the IOR effect might be smaller when the object becomes occluded. The statistical analysis, however, suggests that this is not the case. That is, in the present group, the RT difference between the end location and the "other" location in the occluder condition does not differ significantly from the corresponding RT difference in the context condition, $F(1, 20) < 1$. This strongly suggests that, at least in the present experiment, expectation is as powerful as actual perception in maintaining IOR.

Experiment 2

In Experiment 1, the observer's expectation that the moving object continued to exist behind the occluder was supported by the perceptual evidence that the occluder remained visible throughout the trial. In Experiment 2, we asked whether such perceptual evidence is necessary or whether the belief that the moving object continues to exist behind the occluder can be maintained even when the supporting perceptual evidence is removed, leaving only a memory of the occluding surface.

To this end, we replicated Experiment 1 with one critical change. At the beginning of each trial, the occluder was displayed on the screen as in Experiment 1. After a short interval, the four inducing Pacmen moved outward along diagonal radial paths. As the Pacmen moved outward, the empty pie-shaped sections were progressively reduced so as to create the impression of four disks sliding from under the square-occluding surface (see Figure 4). This procedure left a vivid—albeit nonsensory—impression of the black square remaining on the screen. Shortly after the disks came to rest, the trial continued with the moving object traveling across the screen.

As in Experiment 1, there were two between-subjects conditions: present and absent. On context trials, the object remained present for a brief period at the end of the motion sequence in the present condition, but it disappeared at the end of the motion sequence in the absent condition. On occluder trials, the object appeared to slide behind the edge of the remembered occluding square in both conditions.

An answer to the question of whether IOR can be mediated by the memory of the occluder is provided by whether IOR occurs on occluder trials in the present condition. The presence of a signif-

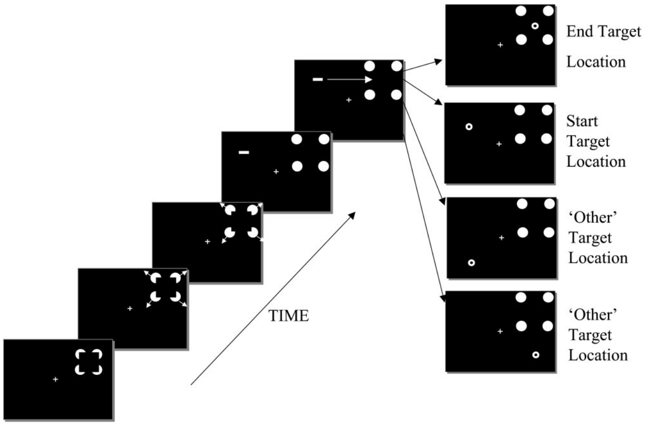

Figure 4. Sequence of events on a typical trial in Experiment 2. After the onset of the fixation cross and occluder, there was a random stimulus onset asynchrony of 1,000–2,000 ms. The gray disks underlying the black square then moved outward along diagonal radial paths and stopped once they had moved beyond the outline of the square. This change took 132 ms to complete and was followed by an interval of 1,000 ms before the dynamic object appeared. Illustrated here is an occluder trial, namely, a trial in which the object disappeared behind the occluder at the end of the motion path. In a context trial, the dynamic object moved along the lower half of the screen. The four possible target locations are illustrated in the four panels on the right side of the figure.

icant IOR effect would support the hypothesis that IOR can be mediated by the mere memory of an occluder.

Method

Observers. Eleven undergraduate students, ages 19–21 years from the University of British Columbia, participated in the present condition for course credit. In the absent condition, we anticipated a null result, namely, the absence of IOR. For that reason, we doubled the number of observers to 22 so as to increase the power of the statistical tests. All observers were right-handed, had normal or corrected-to-normal vision, and were naïve as to the purpose of the experiment.

Stimuli. All stimuli in Experiment 2 were identical to those in Experiment 1.

Design and procedure. Procedures in Experiment 2 were the same as in Experiment 1, with a single exception. After the fixation cross and occluder appeared on the screen, there was a random SOA of 1,000–2,000 ms, followed by a repositioning of the inducing disks. In a series of 15 frames, the gray disks underlying the black square moved outward along diagonal radial paths until they had moved beyond the outline of the square, causing it to meld with the black background and therefore become invisible. This sequence took 132 ms to complete, and the disks moved a total distance of 1.2°. This was followed by an interval of 1,000 ms before the line segment appeared and began to move across the screen.

Results and Discussion

Trials in which observers responded before the onset of the target (i.e., anticipation errors) were excluded from the analysis. This resulted in the elimination of less than 1% of the trials. The results are illustrated in Figure 5.

Median RTs were analyzed in a 2 × 2 × 3 ANOVA, with one between-subjects and two within-subject variables. The between-subjects variable was object continuity: present or absent. One within-subject variable was trial type: occluder or context. The other was target location with respect to the object: start, end, or other. The analysis revealed significant effects of target location, $F(2, 80) = 25.12$, $p < .001$, and object continuity, $F(2, 62) = 4.57$, $p < .05$. The Target Location × Object Continuity interaction was also significant, $F(2, 62) = 11.21$, $p < .001$. No other effects were significant.

An additional 2 (trial type: context, occluder) × 2 (target location: start, end) within-subject ANOVA was conducted to determine whether there was a significant difference in the magnitude of IOR between the start and the end target locations. The analysis revealed a significant effect of target location, $F(1, 31) = 9.22$, $p < .01$, but no significant effect of trial type, $F(1, 31) = 2.980$, $p > .05$, or Trial Type × Target Location interaction, $F(1, 31) = 1.42$, $p > .20$. This means that in Experiment 2, the magnitude of IOR was greater at the end than at the start location. As was the case in Experiment 1, the IOR effect was significant both at the end location ("other" vs. end locations): occluder, $t(10) = 3.61$, $p = .005$, and context, $t(10) = 3.82$, $p = .003$; and at the start location ("other" vs. start locations): occluder, $t(10) = 2.29$, $p < .05$, and context, $t(10) = 2.20$, $p = .05$.

This pattern of results strongly suggests that the expectation that a moving object continues to exist behind an occluding surface can be maintained even when there is no supporting perceptual evidence for the occluding surface. In this respect, the IOR obtained in the present condition of Experiment 2 is based on two separate expectations: One is that the moving object continues to exist after the end of the motion sequence; the other is that the occluder itself continues to exist even though its position is no longer demarcated by any contours, even subjective ones.

The results of Experiment 2 confirm the conclusion drawn in Experiment 1 that observer expectation mediates IOR. Notably, the lack of IOR at both the start and the end locations in the absent condition, coupled with the presence of IOR at both locations in the present condition, confirms the finding in Experiment 1 that the effect of observer expectation is not confined to the occluded location but extends to the starting location as well. This pattern of results is consistent with the account in terms of object files outlined in the *Discussion* section of Experiment 1.

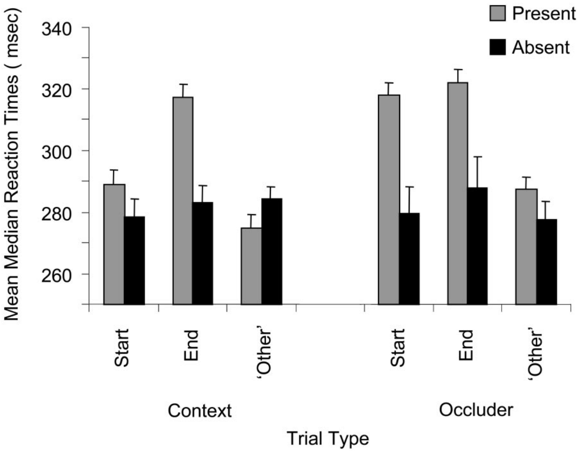

Figure 5. Mean median reaction times in Experiment 2. Error bars represent one standard error of the mean. msec = milliseconds.

Experiment 3

The principal finding in Experiments 1 and 2 was that IOR occurs only if the observer expects the object to continue to exist after the end of the motion sequence. From this it follows that if the observer's expectation were to be disconfirmed, IOR should be greatly reduced or eliminated. We explored this possibility in Experiment 3 by replicating Experiment 1 with one critical modification involving the occluder. Our objective was to convince the observer that in the present condition, the object did not continue to exist behind the occluder. To this end, the occluding square (but not the inducing disks) was moved to an empty screen location shortly after the object appeared to slide behind it (see Figure 6). The key aspect of this manipulation was that removal of the occluder revealed not the object that the observer believed to be hiding behind it but an empty region surrounded by the four inducing disks. We reasoned that this would disconfirm the observers' expectation that the object continued to exist at that location. In turn, we expected such a disconfirmation to reduce the magnitude of the IOR on occluder trials (because the observer could now see that the object no longer persisted behind the occluder) but not on context trials (because the observer could see that the object persisted on the screen at the end of the motion sequence). As in Experiments 1 and 2, there were two between-subjects conditions: present and absent.

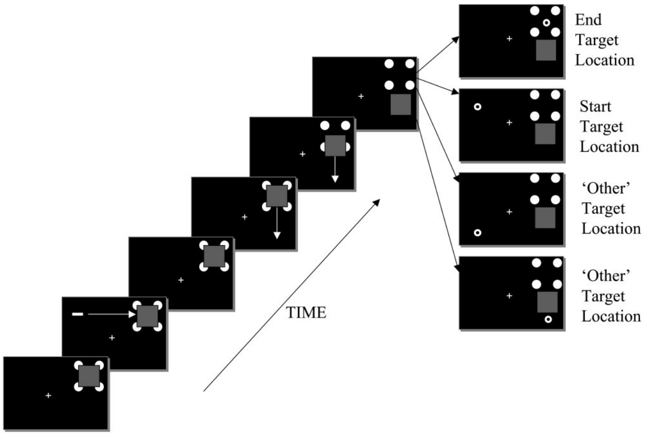

Figure 6. Sequence of events on a typical trial in Experiment 3. After the onset of the fixation cross and occluder, there was a random stimulus onset asynchrony of 1,000–2,000 ms. An object (a short line) then appeared, remained stationary for 304 ms, and moved horizontally across the screen. The motion sequence took a total of 175 ms, and the object subsequently remained at its final position for 50 ms before the occluding square began to move. As it moved, the square slid over the four disks and came to rest on an empty part of the screen, revealing to the observer that the object had not continued to exist behind the occluder. The square completed its motion in approximately 300 ms. After the square's motion sequence was complete, there was an additional interval of 500 ms before the onset of the target. Illustrated here is an occluder trial, namely, a trial in which the object disappeared behind the occluder at the end of the motion path. In a context trial, the object moved along the lower half of the screen. The four possible target locations are illustrated in the four panels on the right side of the figure. Note that in the experiment, the square was red (see text for details), but it is represented in the figure as gray.

Method

Observers. Thirty-four undergraduate students, ages 18–22 years from the University of British Columbia, participated in the experiment for course credit. Seventeen were randomly assigned to the present condition and the remaining 17 to the absent condition. All observers were right-handed, had normal or corrected-to-normal vision, and were naïve as to the purpose of the experiment.

Stimuli. The stimuli in Experiment 3 were identical to those in Experiment 1, except for the occluder. In Experiment 1, the occluder was a Kanizsa square formed by four Pacmen (three-quarter disks) rotated inward to form an illusory square. In Experiment 3, a similar object was formed by a solid, dark red square (5.5 cd/m^2) superimposed on four gray disks (see Figure 6; note that in this figure, the red square appears as gray). The occluder used in Experiment 3 was slightly larger than in Experiment 1, measuring 4.25° × 4.25°, with each disk having a radius of 1.5° and the square portion measuring 3.25° × 3.25°. If the occluder was in one of the lower quadrants of the screen, the square moved upward, whereas if the occluder was in one of the upper quadrants, the square moved downward. As it moved, the square slid over the four disks and came to rest on an empty part of the screen.

Design and procedure. The procedures in Experiment 3 were the same as in Experiment 1, with the following exceptions: Each trial began with a display of the fixation cross and the occluder consisting of the red square superimposed on the four disks. After a random SOA of 1,000–2,500 ms, a short line (i.e., the object) was presented in the center of one of the four quadrants of the screen, remained stationary for 304 ms, and then moved horizontally across the screen, as in Experiment 1. The motion sequence took a total of 175 ms, and the object subsequently remained at its final position for 50 ms. From that point in time, the display sequence differed for the present and absent conditions as follows: On context trials in the present condition, the object remained visible in its final position as the red square began to move. The square completed its motion in 304 ms and moved a total of 5° of visual angle. After the square's motion sequence was complete, the object remained visible on the screen for an additional 500 ms before the onset of the target. Thus, the object remained visible on the screen for a total of 854 ms from the end of its motion sequence to the appearance of the target. The occluder trials in the present condition were the same as the context trials, except that the object appeared to slide behind the red square at the end of the motion path. In this condition, when the red square moved from its initial position, it revealed to the observer that the moving object had not continued to exist behind the occluder. Trials in the absent condition were the same as in the present condition, with a single exception: The object invariably disappeared from the screen 50 ms after the end of its motion sequence.

Results and Discussion

Trials in which the observers responded before the onset of the target (i.e., anticipation errors) were excluded from the analysis. This resulted in the elimination of less than 1% of the trials. The results are illustrated in Figure 7.

Median RTs were analyzed in a 2 × 2 × 3 ANOVA, with one between-subjects and two within-subject variables. The between-subjects variable was object continuity: present or absent. One within-subject variable was trial type: occluder or context. The other was target location with respect to the object: start, end, or other. The analysis revealed significant effects of target location, $F(2, 68) = 36.60$, $p < .001$, and object continuity, $F(1, 34) = 4.57$, $p < .05$. The Trial Type × Object Continuity interaction was also significant, $F(1, 34) = 9.28$, $p < .005$, as was the Target Location × Object Continuity interaction, $F(2, 68) = 23.54$, $p < .001$. No other effects were significant.

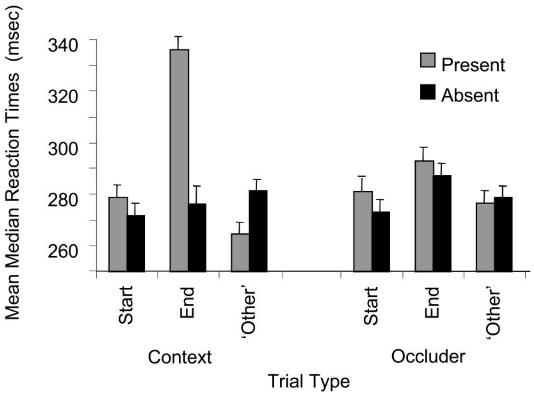

Figure 7. Mean median reaction times for trials in Experiment 3. Error bars represent one standard error of the mean. msec = milliseconds.

As was the case in Experiments 1 and 2, there was a significant IOR effect in the present condition at both the end and start locations in the context trials—for start: context, $t(16) = 4.00$, $p = .001$, for end: context, $t(16) = 5.44$, $p < .001$; but only at the end location in the occluder trials—for start: $t(16) = 0.975$, $p > .3$, for end: $t(16) = 3.15$, $p < .01$.[3]

In addition, median RTs were analyzed in a 2 × 3 repeated measures ANOVA. One variable was trial type (occluder or context); the other was target location (start, end, or other). The analysis revealed significant effects of both target location, $F(2, 16) = 42.53$, $p < .001$, and trial type, $F(1, 16) = 7.83$, $p < .01$. The interaction effect was also significant, $F(2, 16) = 13.55$, $p < .001$. This confirms the evidence in Figure 7 that, in the present group, the magnitude of IOR was greater in the context condition than in the occluder condition. This interaction indicates that although a large IOR was found in the context condition, in which it could clearly be seen that the object continued to exist on the screen at the end of its motion sequence, significantly less IOR was found in the occluder condition, in which the observer saw that the object did not continue to exist behind the occluder. This means that when the observer's expectation that the object continues to exist behind the occluder is disconfirmed, IOR is significantly reduced.

In conjunction with the results of Experiments 1 and 2, the outcome of Experiment 3 buttresses the conclusion that IOR is mediated by observer expectation. The results of the absent condition, illustrated in Figure 7, replicate the corresponding results in Experiments 1 and 2. Notably, the lack of IOR at both the start and end locations in the absent condition, coupled with the presence of IOR at both locations in the present condition, gives further support to the claim that the effect of observer expectation is not specific to the occluded location but is a general effect that extends to the starting location as well. This pattern of results can be encompassed within the theoretical framework based on object files, outlined in the *Discussion* section of Experiment 1.

Experiment 4

The main finding in Experiment 3 was that the magnitude of IOR was reduced when the observer's expectation that the object continued to exist behind the occluder was disconfirmed. The procedures of Experiment 3, however, allow for at least two additional accounts. First, it is possible that the occluding surface, which was salient because of its color and motion, might have caused attention and therefore IOR to be redirected from the object to the occluder itself. Second, it is possible that the observer might have expected that the object was somehow stuck underneath the occluder and moved with it to the occluder's new location. Both these hypotheses are plausible alternatives to the "disconfirmation" account and could explain why, in Experiment 3, IOR was reduced when the target was presented at the occluder's preshift location.

Experiment 4 was designed to test both these options by including trials in which the target was presented on top of the occluder in its new location. On both alternative hypotheses, the occluder would be at the focus of attention, and a significant IOR effect should therefore be in evidence at the occluder's new location.

Method

Stimuli and procedures were the same as in the present condition in Experiment 3, with a single exception concerning the location of the target. Whereas in Experiment 3 the target could appear in one of four locations, in Experiment 4 it appeared in one additional location, namely, on top of the red square in its new location. Seventeen observers drawn from the same population as in the preceding experiments participated in Experiment 4.

Results and Discussion

Trials in which the observers responded before the onset of the target (i.e., anticipation errors) were excluded from the analysis. This resulted in the elimination of less than 1% of the trials. The results are illustrated in Figure 8.

The results illustrated in Figure 8 closely replicate the corresponding results of Experiment 3 (see Figure 7) in that IOR was substantially reduced on occluder trials as compared with context trials. Median RTs were analyzed in a 2 (trial type: context or

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[3] It is worth noting that the object-based IOR effect obtained in Experiment 3 is considerably larger than the corresponding IOR obtained in Experiment 1 (72 ms vs. 38 ms). One plausible reason is that the interval elapsing from the end of the object motion to the onset of the target was longer in Experiment 3 than in Experiment 1 (725 ms vs. 400 ms). Given that the strength of IOR is known to increase at SOAs beyond about 300 ms (Klein, 2000), an SOA of 725 ms would result in IOR of greater magnitude. It is also worth noting that the magnitude of IOR obtained in all of the present experiments was larger than the IOR typically obtained in other studies that used dynamic displays (e.g., 38 ms in Experiment 1, 43 ms in Experiment 2, and 72 ms in Experiment 3 vs. less than about 20 ms in the studies of Yi et al., 2003, and Tipper et al., 1994). One reason may be that in the present experiments, attention was deployed directly and naturally to the object itself (due to its abrupt onset and its motion) rather than being deployed indirectly by means of a cue. Thus, the relatively large IOR obtained in the present study may stem from the fact that IOR occurred in direct response to the object itself rather than being mediated by a cue. Another possibility may have to do with the distribution of attention among the objects in the display. In earlier studies, such as those of Tipper et al. (1991) and Ro and Rafal (1999), the display contained multiple objects that might have competed for limited attentional resources. In contrast, the present display contained only a single object, thus enabling all resources to be concentrated on the object of interest.

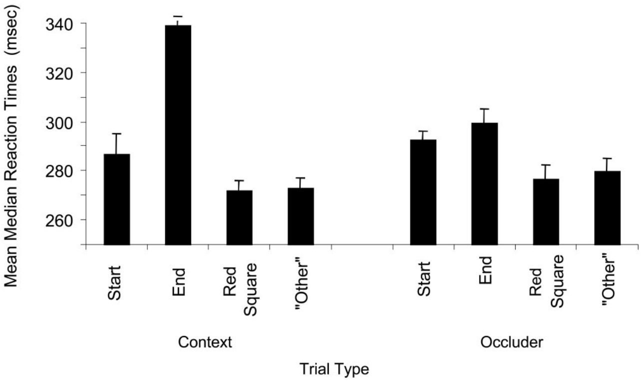

Figure 8. Mean median reaction times for trials in Experiment 4. Error bars represent one standard error of the mean. msec = milliseconds.

occluder) × 4 (target location: start, end, other, red square) within-subject ANOVA. The analysis revealed a significant effect of target location, $F(3, 48) = 25.05$, $p < .001$, and a significant Trial Type × Target Location interaction, $F(3, 48) = 4.49$, $p = .007$. No other effects were significant.

A separate ANOVA was conducted to check whether the magnitude of IOR was greater in the context than in the occluder condition, as was the case in Experiment 3. The analysis consisted of two within-subject variables: trial type, at two levels (context or occluder), and target location, at two levels (end and other). The analysis revealed significant effects of trial type, $F(1, 16) = 5.89$, $p < .03$, and target location, $F(1, 16) = 86.68$, $p < .001$, and a significant Trial Type × Target Location interaction, $F(1, 16) = 11.07$, $p = .004$. The outcome of this analysis confirms the finding in Experiment 3 that the magnitude of the IOR effect is significantly reduced when the observer's expectation that the object continues to exist behind the occluder is disconfirmed.

The result of principal interest in Figure 8 is the complete absence of IOR when the target was presented on top of the occluder in its new location. This finding is inconsistent with the possibility that the observers believed the object moved with the red square or that the red square itself captured attention. The data in Figure 8 were analyzed in a 2 (trial type: context or occluder) × 2 (target location: other or red square) within-subject ANOVA. The analysis revealed no significant effects of trial type, $F(1, 16) = 0.75$, $p = .40$; target location, $F(1, 16) = 0.13$, $p = .72$; or Trial Type × Target Location interaction, $F(1, 16) = 0.01$, $p = .93$. It is clear that, with respect to the magnitude of the IOR effect, the red square was equivalent to any other empty screen location where the object had not been presented on that trial.

In summary, although entirely consistent with the disconfirmation hypothesis, the absence of IOR when the target was presented on the red square in its new location is inconsistent both with the hypothesis that the observers believed the object to have moved with the red square and with the hypothesis that the occluder itself captured attention because of its color and motion.

General Discussion

The primary objective of the present study was to determine whether observer expectation mediates IOR. In Experiment 1, IOR was obtained only when the observer had developed an expectation that the object continued to exist behind an occluder. IOR did not occur when the observer expected that the object ceased to exist after it slid behind the occluder. In Experiment 2, IOR to an occluded object was obtained even when awareness of the occluder itself was based not on physical evidence but on a memory representation. Finally, Experiments 3 and 4 showed that the IOR effect is significantly reduced when the observer's expectation that the object continued to exist behind the occluder is disconfirmed. We conclude that observer expectation is a powerful determinant of IOR to an occluded object. We now consider how the present findings relate to previous findings and interpretations in the IOR literature.

Does Object-Based IOR Require a Visible Object?

Previous research has provided conflicting evidence as to whether object-based IOR occurs to an object that is not visible when the cue is presented. Tipper et al. (1999) concluded that object-based IOR is obtained only when the object is visible when cued. If the object is no longer on view when the cue is presented, IOR does not occur. Additional support for this conclusion comes from visual search studies showing that IOR is found only when the search array remains on the screen until the target appears. If the array is removed before the onset of the target, IOR is no longer found (Klein & MacInnes, 1999; Takeda & Yagi, 2000).

This view is also supported by portions of the present results. Consider, for example, the results for the context condition in Experiment 1, in which the dynamic object was never occluded at the end of the motion path. It can be seen that IOR occurred in the present group, for which the object remained on view until the target was presented, but not in the absent group, for which the object disappeared 400 ms before the onset of the target. Notably, consistent with Tipper et al. (1994) and with the visual search findings, IOR did not occur when the target was presented well after the object had been removed from the screen.

In apparent contradiction to studies showing that a visible object is necessary for IOR, Yi et al. (2003) demonstrated that IOR can indeed occur to an occluded object. Specifically, they showed that IOR occurs to an object that is occluded when it is cued, as was the case in Tipper et al.'s (1994) study, or is occluded when the target appears, as in the present study, or both. Yi et al. suggested that Tipper et al. did not obtain IOR in their study because the occluder was an object that could attract attention in its own right. Thus, the object singled out by the cue may not have been the dynamic object hiding behind the occluder but rather the occluding object itself. This misdirection of attention was avoided in Yi et al.'s study by means of several small but critical changes.

First, they reduced the visual prominence of the occluder so that it was more like an extended surface than another object. This discouraged attention from being drawn to the occluder rather than to the object behind it. Second, when the object slid behind the occluder, it did so in stages (a decretion signal), creating a realistic impression of an object becoming gradually occluded. Similarly, when the object reappeared from behind the occluder, it did so in stages (an accretion signal). These changes caused attention to be directed to the object behind the occluder rather than to the occluder itself. As a result, it was the dynamic object that was cued rather than the occluder, and IOR was therefore obtained.

The Role of Expectation

Collectively, the studies of Tipper et al. (1994), Yi et al. (2003), and the present study provide converging evidence for the roles of visibility and expectation in object-based IOR. Visibility and expectation influence IOR in different ways, depending on whether the object is visible throughout the motion sequence or whether it becomes occluded. If the object is not occluded during its motion trajectory (as was the case on context trials in the present experiments), what determines IOR is whether the object remains on view immediately before the onset of the target. If the object remains on view, IOR occurs; if the object disappears for an interval before the onset of the target, IOR does not occur.

If, however, the object is occluded at some point in its motion sequence (as was the case on occluder trials in the present experiments), the primary determining factor is not object visibility but the observer's expectation as to whether the object continues to exist behind the occluder. If the observer expects the object to continue to exist, IOR occurs; if the object is expected to cease to exist, IOR does not occur. At a more general level, these findings point to a considerable involvement of high-level processes in IOR.

Relating the Present Findings to the Real World

It may be informative to relate the present laboratory findings to everyday viewing in the real world. It may be a truism to say that if a real-world object suddenly disappears from view (without being occluded or moving out of visual range), it is because the object has ceased to exist. Thus, if a real-world object can still be seen, we can safely conclude that it continues to exist. By the same token, if an object disappears into thin air, we can safely surmise that it has ceased to exist. The implications of this reasoning for IOR are straightforward. Because there would be no advantage to maintaining IOR to an object that no longer exists, IOR should not occur to an object that suddenly disappears. This was the case for the absent condition in Experiment 1.

The primary exception to this reasoning is, of course, the case of occlusion. If an object is occluded, it may continue to exist behind the occluding surface, even though it is not visible. As such, something other than the visibility of the object must determine whether IOR occurs to an occluded object. The present findings indicate that expectation is one such factor. That is, IOR is observed only if the occluded object is expected to continue to exist behind the occluding surface.

References

Jordan, H., & Tipper, S. P. (1998). Object-based inhibition of return in static displays. *Psychonomic Bulletin & Review, 5,* 504–509.

Jordan, H., & Tipper, S. P. (1999). Spread of inhibition across an object's surface. *British Journal of Psychology, 90,* 495–507.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24,* 175–219.

Klein, R. M. (1988, August 4). Inhibitory tagging system facilitates visual search. *Nature, 334,* 430–431.

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences, 4,* 138–147.

Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. *Psychological Science, 10,* 346–352.

Leek, E. C., Reppa, I., & Tipper, S. P. (2003). Inhibition of return for objects and locations in static displays. *Perception & Psychophysics, 65,* 388–395.

Leslie, A. M., Xu, F., Tremoulet, P. D., & Scholl, B. J. (1998). Indexing and the object concept: Developing "what" and "where" systems. *Trends in Cognitive Sciences, 2,* 10–18.

Lupiáñez, J., & Milliken, B. (1999). Inhibition of return and the attentional set for integrating versus differentiating information. *Journal of General Psychology, 126,* 392–418.

Lupiáñez, J., Milliken, B., Solano, C., Weaver, B., & Tipper, S. P. (2001). On the strategic modulation of the time course of facilitation and inhibition of return. *Quarterly Journal of Experimental Psychology, 54A,* 753–773.

Maylor, E. (1985). Facilitatory and inhibitory components of orienting in visual space. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI: Mechanisms of attention* (pp. 189–203). Hillsdale, NJ: Erlbaum.

Miller, J. (1988). A warning about median reaction time. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 539–543.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 531–556). Hillsdale, NJ: Erlbaum.

Reppa, I., & Leek, E. C. (2003). The modulation of inhibition of return by object-internal structure: Implications for theories of object-based selection. *Psychonomic Bulletin & Review, 10,* 493–502.

Ro, T., & Rafal, R. D. (1999). Components of reflexive visual orienting to moving objects. *Perception & Psychophysics, 61,* 826–836.

Spelke, E. S., Kestenbaum, R., & Simons, D. J. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology, 13,* 113–142.

Takeda, Y., & Yagi, A. (2000). Inhibitory tagging in visual search can be found if search stimuli remain visible. *Perception & Psychophysics, 62,* 927–934.

Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centered inhibition of return of visual attention. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 43A,* 289–298.

Tipper, S. P., Jordan, H., & Weaver, B. (1999). Scene-based and object-centered inhibition of return: Evidence for dual orienting mechanisms. *Perception & Psychophysics, 61,* 50–60.

Tipper, S. P., Weaver, B., Jerreat, L. M., & Burak, A. L. (1994). Object-based and environment-based inhibition of return in visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 478–499.

Yi, D.-J., Kim, M.-S., & Chun, M. (2003). Inhibition of return to occluded objects. *Perception & Psychophysics, 65,* 1222–1230.

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