OBSERVATION

Inhibition of Return: Dissociating Attentional and Oculomotor Components

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Inhibition of return (IOR) describes a performance decrement for stimuli appearing at recently cued locations. Both attentional and motor processes have been implicated in the IOR effect. The present data reveal a double dissociation between the attentional and motor components of IOR whereby the motor-based component of IOR is present when the response is oculomotor, and the attention-based component of IOR is present when the response is manual. These 2 distinct components should be considered and studied separately, as well as in relation to each other, if a comprehensive theory of IOR is to be achieved.

When attention is drawn to a location in space, the detection of targets appearing there is initially facilitated, then impaired, relative to other locations. The latter impairment at the recently attended location was first demonstrated by Posner and Cohen (1984) and has come to be known as *inhibition of return* (IOR), connoting the idea that attention is biased away from a location it has recently inspected. The method initially used by Posner and Cohen to measure IOR is still commonly applied: A visual precue directs attention to one of several possible target locations, then when the target subsequently appears, it is either at the cued location or at an uncued location. IOR is the performance decrement at the cued location relative to other locations when the interval between the onset of the cue and the onset of the target is more than approximately 300–400 ms. Eye movements to the cue are usually discouraged to ensure that the differences in reaction time (RT) are due to the locus of attention rather than gaze.

IOR may increase the efficiency of visual search by preventing attention from being squandered on recently visited locations, biasing it instead toward novel locations, a suggestion that has found empirical support (e.g., Klein, 1988; Klein & McInnes, 1999). A fundamental assumption of this characterization of IOR is that attention is biased away from the cued location. This assumption has been questioned, however, and an alternative proposal has been put forward that IOR represents a reluctance to respond to the previously cued location (Klein & Taylor, 1994). That is, once a location is cued and a response to that location has been inhibited successfully, participants are slower to execute that response when a target appears in the same location. Whether the

IOR effect represents a change in attentional bias or response-related processes has been a source of considerable debate (see Taylor & Klein, 1998, for a review). The currently held view of IOR is that these two seemingly contradictory accounts may both be correct, with both attentional and motor components contributing to IOR (e.g., Abrams & Dobkin, 1994b; Kingstone & Pratt, 1999; Klein & Dick, 2002; Taylor & Klein, 2000).

Strong evidence that IOR biases attention comes from the observation that IOR can exercise the same attentional influence on target processing as early facilitation. Reuter-Lorenz, Jha, and Rosenquist (1996) demonstrated this empirically by selecting a number of factors known to influence the facilitative effects of attention at short cue-target intervals to systematically observe their effects on IOR at long cue-target intervals. Reuter-Lorenz et al. reasoned that if both IOR and early facilitation effects bias the same stage of processing, then they should be influenced by the same factors. Reuter-Lorenz et al. found that IOR interacts with target luminance and target modality (perceptual factors that are known to influence cuing effects) but not with response modality (a motor factor that should not affect attention). This pattern is consistent with IOR having an attentional, but not a motor, effect on target processing. Considered together with studies that find an IOR effect in nonspatial responses and identification tasks (e.g., Kingstone & Pratt, 1999; Lupianez, Milan, Tornay, Madrid, & Tudela, 1997; Pratt, Kingstone, & Khoe, 1997), in visual search (Klein, 1988; Klein & McInnes, 1999; Müller & von Mühlenen, 2000), and when using measures of perceptual sensitivity instead of RT (Handy, Jha, & Mangun, 1999; Klein & Dick, 2002), there is ample evidence of an attentional component in IOR.

Nevertheless, doubt about IOR being a purely attentional effect arises from several findings demonstrating fundamental differences between the initial facilitation and the subsequent inhibition at the cued location. For instance, IOR is not generated indiscriminately at any location to which attention is allocated. Posner and Cohen (1984) observed IOR following the exogenous allocation of attention to a location, that is, when a spatially nonpredictive cue drew attention to a location reflexively by brightening briefly. When spatial attention was allocated endogenously, that is, in response to a central and spatially predictive arrow cue, IOR was

no longer observed. Another indication came from measures of perception at the cued location. If IOR is an attentional effect, one would expect IOR to influence perceptual judgments (such as temporal order judgments) and illusions (such as illusory line motion). Although attention has an effect on temporal order judgments and perceptual illusions when the cue-target interval is less than 300 ms, at later cue-target intervals during which IOR is expressed, an IOR effect on temporal order judgments (e.g., Maylor, 1985; Posner, Rafal, Choate, & Vaughan, 1985) and illusory line motion (Schmidt, 1996) is not observed. Together, these results suggest that IOR does not simply reflect an effect of attention, leading researchers to suggest that IOR can reflect a nonattentional mechanism, such as a motor bias.

In line with a motor-based explanation, networks controlling eye movements have been implicated in the generation of IOR. A seminal study demonstrating that IOR has an important relationship to eye movements was that of Rafal, Calabresi, Brennan, and Sciolto (1989), who found that IOR was generated when an eye movement was prepared regardless of whether the eye movement preparation was initiated by an informative arrow (endogenous cue) or a noninformative peripheral event (exogenous cue). When an eye movement was not prepared, no IOR was observed. This link between IOR and eye movements has led to the suggestion that IOR involves oculomotor response mechanisms and, in particular, the superior colliculus (SC), which is a midbrain structure that plays a critical role in the execution and control of eye movements (Clohessy, Posner, Rothbart, & Vecera, 1991; Rafal et al., 1989; Sapir, Soroker, Berger, & Henik, 1999).

Supporting evidence for the role of the SC in IOR would appear to come from a study by Abrams and Dobkin (1994a), who found that the IOR effect interacts with a phenomenon known as the fixation offset effect (FOE). The FOE arises when the fixation point is removed from a display just as a peripheral target appears, resulting in faster saccades to a target stimulus relative to when the fixation point remains on the screen. This effect appears to reflect a mutually inhibitory relationship between fixation and saccade neurons of the SC (Dorris, Pare, & Munoz, 1997). The sudden removal of sensory input triggered by extinguishing fixation reduces activity among the fixation neurons. This, in turn, releases the saccade neurons from inhibition, enabling faster saccades to other stimulated regions in the visual field. Thus, when Abrams and Dobkin (1994a) found that IOR was smaller when the fixation point remained on the screen than when the fixation point was removed, they interpreted this IOR × FOE interaction as indicating "active foveation of a visible fixation point . . . inhibits saccade production by the same mechanism through which inhibition of return operates" (p. 486). In agreement with Abrams and Dobkin's conclusion, this result has routinely been cited as evidence that IOR reflects, at least in part, a motor effect generated in the SC (e.g., see Abrams & Pratt, 2000; Klein, 2000).

With evidence accruing on both sides of the debate, it is perhaps not surprising that several researchers have proposed that both attention and oculomotor components are involved in IOR. For instance, Taylor and Klein (2000) came to this conclusion when they produced a pattern of results that was consistent with IOR reflecting a motor bias when eye movements were executed and consistent with IOR reflecting an attentional bias when the eyes remained fixed (see also Abrams & Dobkin, 1994b; Kingstone & Pratt, 1999; Klein & Dick, 2002). Although it is clear from past

research that IOR may reflect both perceptual and motor processes, it has yet to be determined whether these two components are separable from each other and, if so, the conditions under which they would be expressed. This state of affairs led us to attempt to replicate two seemingly contradictory findings that were taken as evidence that IOR (a) influences perception at the cued location and (b) influences oculomotor responses to the cued location. The first finding we wished to replicate was that of Reuter-Lorenz et al. (1996), who measured IOR using manual responses and, as discussed above, found that IOR interacts with target intensity, in the form of luminance, with larger IOR for dim targets than for bright targets. The second finding we wished to replicate was that of Abrams and Dobkin (1994a), who measured IOR using saccadic responses and found that IOR interacts with an effect that is thought to be specifically oculomotor (the FOE). A comparison of these two findings, illustrated in the 2 × 2 matrix in Figure 1, suggests that attention-based and motor-based components of IOR may separate along the line of response modality, such that (a) IOR reflects an attentional effect, namely, an interaction with target luminance when eye movements are withheld and a manual response is executed, and (b) IOR reflects a motor effect, namely, an interaction with the FOE when an oculomotor response is executed. It is important to note that this hypothesis is consistent with several studies that have shown key differences in the nature of IOR when it is measured using saccadic rather than manual responses (e.g., Abrams & Pratt, 2000; Briand, Larrison, & Sereno, 2000; Kingstone & Pratt, 1999; Taylor & Klein, 2000). If these two components of IOR are truly separable across response modality, then it follows that one should be able to produce a double dissociation, such that when the response is manual, IOR interacts with target luminance but not with the FOE, and conversely, when the response is oculomotor, IOR interacts with the FOE but not with target luminance (see Figure 1).

We should also note that it was particularly important to us to examine the nature of any interaction between IOR and FOE, because there is reason to be concerned that the original observa-

Figure 1. Illustration of the logic underlying the experiment. We suggest that inhibition of return (IOR) may be dissociable along the line of response modality, such that an interaction with the fixation offset effect (FOE) would occur only for oculomotor responses and an interaction with target luminance would occur only for manual responses. See the text for more details.

tion by Abrams and Dobkin (1994a) may not be replicable. Inspection of their data reveals that in both conditions in which the fixation point remained on (which is the standard condition under which IOR is normally observed), the difference between the cued and the uncued locations was less than 4 ms. In contrast, when the fixation point was extinguished just as a target was presented, IOR grew to approximately 13 ms (in Abrams & Dobkin, 1994a, Experiment 3). Thus, the interaction between IOR and FOE appears to reflect a failure to generate robust IOR when the fixation point remains on (a condition that normally produces large and reliable IOR effects) rather than the modulation of a significant IOR effect when the fixation point is removed. A replication of this unusual interaction between FOE and IOR would thus increase confidence in Abrams and Dobkin's conclusions.

In the following experiment, participants made left or right saccadic responses to the target for half the blocks, and for the other half, the participants pressed a left or right button in response to the target. On the basis of Reuter-Lorenz et al. (1996), IOR should interact with target luminance, which would provide evidence for an attentional component in IOR that is expressed when the eyes remain stationary. On the basis of Abrams and Dobkin (1994a), IOR should interact with the FOE, which would in turn provide evidence for an oculomotor component. If this fixation offset manipulation is indeed tapping into specifically oculomotor responses, it should be absent for manual responses (e.g., see Kingstone & Klein, 1993), and an interaction with manual IOR would not be expected.

Method

Participants

Fourteen undergraduate psychology students at the University of British Columbia were offered course credit for their participation. All had normal vision. The data from 3 participants were removed, in one case due to equipment problems and in two others because of poor performance.

Apparatus, Procedure, and Design

Participants were seated 57 cm in front of an 18-in. (45.72-cm) 60-Hz monitor with their heads stabilized in a chin rest. Stimulus presentation and data collection were controlled by an 80-MHz 486-DX2 personal computer. Movements of the left eye were sampled every 4 ms using an infrared photoelectric eye-monitoring device (Applied Science Laboratories Model 210) mounted on a head frame. Rather than fully restraining the participant to prevent head movements, the experimenter was present in the room for the duration of the experiment to manually compensate for slight changes in head position by adjusting for drifts in fixation readings as they appeared. The sequence of events in a trial are shown in Figure 2. The display, shown on a black screen (6.7 cd/m^2), consisted of a central fixation crosshair flanked $7.0°$ to the left and right by two white squares; each square was $2.0° \times 2.0°$ in size. After 800 ms, the cue appeared in the form of a 300-ms thickening to $0.30°$ of the $0.10°$ line forming one of the two squares. The target was a circle, $0.8°$ in diameter, which appeared 1,160 ms after the onset of the cue, either in the cued placeholder or in the opposite placeholder. Targets could be either bright (104.1 cd/m^2) or dim (10.4 cd/m^2). The fixation point could either remain on the screen or be removed from the display simultaneous with the onset of the target. The target remained on the screen until 200 ms after the participant's response. Participants were instructed to keep their eyes on the fixation crosshair until the target appeared.
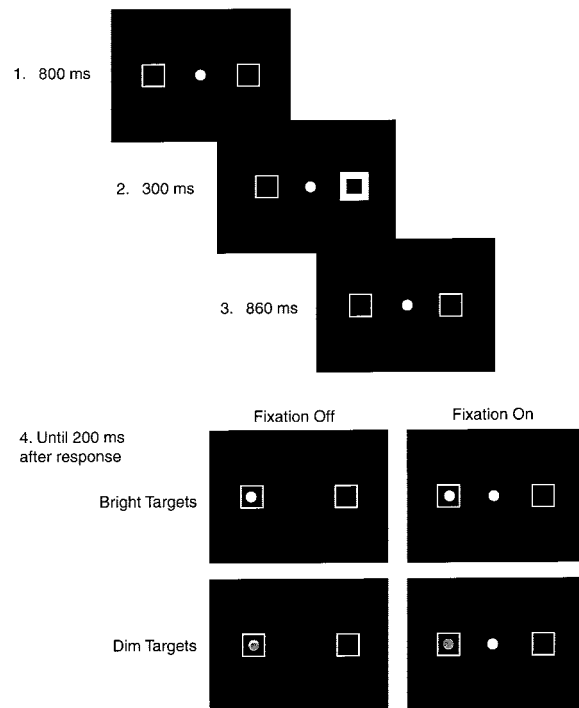

Figure 2. The sequence of events making up a trial is shown from the beginning of the trial to a response. First, the trial begins with a fixation point and two possible target locations. Second, after 800 ms, the cue appears for 300 ms. Third, a delay of 860 ms precedes the onset of the target. Fourth, the target appears, in this case in the cued location. It can be either bright or dim, and the fixation point either stays on or is removed as the target appears.

There were six blocks of 64 trials each in total, and the type of response made to the target was manipulated between sets of three consecutive blocks, that is, participants made one type of response for the first three blocks and then changed to the second type of response for the remaining three blocks. In the manual blocks, participants were instructed to withhold an eye movement throughout the trial and to press the left button (the Z key of a standard QWERTY keyboard) if the target appeared in the left square or the right button (the *slash* key) if the target appeared in the right square. These two buttons were marked with bright, textured stickers. The participants' RT was recorded as the duration from the onset of the target to the onset of the button-press response. In the saccade condition, participants were instructed to keep their gaze on the central fixation point until the target appeared, at which time they would execute an eye movement to it. In the saccade trials, the latency of the first eye movement after the onset of the target was recorded. The eye movement latency was defined as the time from the onset of the target to the moment the eye's movement began to exceed a threshold of $10.0°$/s, so long as the movement's velocity then accelerated to $35.0°$/s and maintained that velocity for more than 10 ms.

Analysis

Three-way analyses of variance (ANOVAs) were conducted on the RT and percentage correct data for both manual and saccadic responses, with IOR (cued or uncued), fixation offset (fixation on or off), and luminance (bright or dim) as factors. Among the manual response data, trials were excluded for two reasons: (a) anticipations, that is, manual responses executed either before the onset of the target or within 100 ms of its onset and (b) trials on which an eye movement was executed. This accounted

for 9.6% of the total number of trials. Errors (trials on which the participants pressed the wrong button) made up less than 1.0% of the remaining trials and were also excluded from the RT analysis. Among the saccade response data, trials were excluded if (a) the participant made an eye movement before or within 80 ms of the target onset or (b) the participant blinked. On the basis of these criteria, 2.1% of the total saccade trials were excluded. Just 1.7% of the remaining trials were errors (trials in which the participant executed a saccade in the wrong direction). There were no significant effects among the error data (see Table 1).

Results

Saccadic RT (SRT)

Figure 3 and Table 1 show the results for the saccadic responses. All three main effects were significant: IOR, with faster responses to the uncued location, $F(1, 10) = 21.33$, $p < .01$; luminance, with faster responses to bright targets, $F(1, 10) = 16.07$, $p < .01$; and the FOE, with faster responses when the fixation point was removed, $F(1, 10) = 13.22$, $p < .01$. IOR interacted with the FOE, $F(1, 10) = 4.98$, $p < .05$, with larger IOR (cued−uncued SRT) for fixation on (35 ms) than for fixation off (13 ms) conditions. There were no other significant interactions, including the interaction of IOR with luminance ($F < 1$).

Manual RT

Figure 3 and Table 1 also depict the results for the manual responses. Two main effects were significant: IOR, $F(1, 10) = 8.08$, $p < .05$, and luminance, $F(1, 10) = 25.17$, $p < .01$. The FOE was not significant, $F(1, 10) < 1$. Luminance interacted with IOR, $F(1, 10) = 7.46$, $p < .05$, with larger IOR for dim (26 ms) than bright targets (14 ms). No other interactions were significant, including the interaction between IOR and FOE, $F(1, 10) = 3.22$, $p > .10$.[1]

In an additional ANOVA, we included response type as a factor along with IOR, luminance, and fixation offset. Given the selective influence of luminance on IOR for manual responses and the selective influence of the FOE on IOR for saccadic responses, we expected that these two interactions would express themselves as a three-way interaction involving response type. Indeed, these interactions were significant: the interaction between response type, IOR, and luminance, $F(1, 10) = 5.12$, $p < .05$, agrees with our finding that IOR varied with luminance for manual responses

but not saccadic responses, and the interaction between response type, IOR, and FOE, $F(1, 10) = 15.66$, $p < .01$, agrees with our finding that IOR varied with the FOE for saccadic responses but not for manual responses. The three-way interaction between luminance, fixation offset, and IOR was also significant, $F(1, 10) = 6.14$, $p < .05$, reflecting the fact that, ignoring response type, fixation status mattered more for bright than for dim stimuli. There was no significant four-way interaction ($F < 1$).

Discussion

The results of this study are as follows:

1. When saccadic responses were made to the target, we found an interaction of IOR with the FOE, consistent with there being an oculomotor component involved in IOR. It should be noted that the interaction we observed is opposite to the interaction observed by Abrams and Dobkin (1994a). The importance of this finding, and why we consider it to be a correction of the Abrams and Dobkin observation, is discussed in detail below.

2. For saccadic responses, IOR was additive with target luminance.

3. When manual responses were made to the target, we found that IOR interacted with target luminance such that IOR increased as targets dimmed (replicating Reuter-Lorenz et al., 1996).

4. For manual responses, there was no interaction between IOR and FOE.

Together these data satisfy the conditions for a double dissociation between motor and attentional components of IOR as depicted in Figure 1, with the separation occurring at the point of response type, that is, between oculomotor and manual responses. The motor component of IOR is expressed during saccadic responses as a significant decrease in IOR when the fixation point is removed, a subcortical effect realized at the level of the SC. The attentional component is expressed during manual responses as a significant interaction between IOR and target luminance. It is important to note that IOR neither interacted with target luminance for saccadic responses nor significantly interacted with the FOE for manual responses. In sum, the results indicate that motor-based and attention-based IOR are separable, such that motor-based IOR

Table 1

Performance Results for Saccadic and Manual Responses

		Bright		Dim	
Variable	Fixation	Cued	Uncued	Cued	Uncued
Reaction time (ms)					
Saccade	On	248.7	207.5	262.9	233.7
	Off	197.7	186.6	213.3	199.5
Manual	On	312.0	300.7	326.5	310.9
	Off	309.7	292.5	340.2	303.8
Accuracy (%)					
Saccade	On	98.5	97.7	98.4	97.7
	Off	97.7	98.1	99.2	99.1
Manual	On	99.1	99.6	99.0	100.0
	Off	100.0	98.8	98.6	98.6

[1] It should be noted that there is a trend for IOR to be larger when the fixation point is extinguished. Although this trend is opposite to what was observed for saccadic responses, we thought it was important to determine whether it was reflecting a reliable trend in participant performance. We examined the pattern of data among individual participants in this experiment and found that the trend was not sufficiently stable to warrant further interpretation. Seven participants' data were consistent with the overall pattern, and 4 participants' data showed the reverse, $\chi^2(1) = 0.82$, $p > .25$. For comparison, we also ran this chi-square test for the individual participant pattern contributing to the two significant interactions (between IOR and FOE among saccadic responses and between IOR and luminance for manual responses), and on both occasions it was significant, $\chi^2(1) = 4.45$, $p < .05$.

Saccadic responses
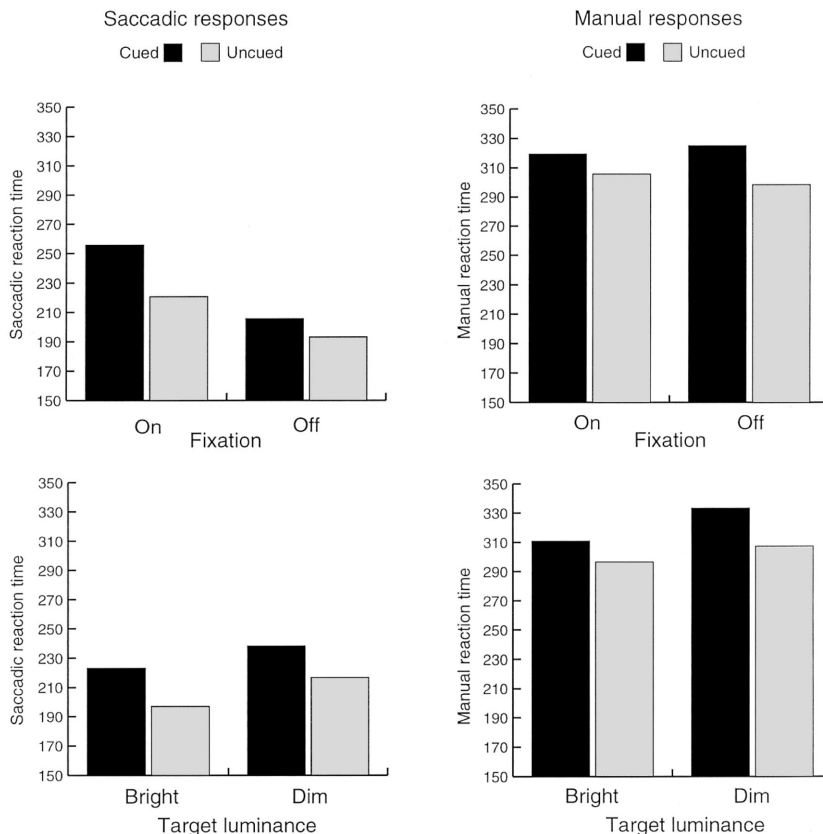Cued ■ Uncued □

Manual responses
Cued ■ Uncued □

Figure 3. Saccadic and manual reaction times (in milliseconds) to cued and uncued targets in an inhibition of return (IOR) experiment. For saccadic responses, the interaction between IOR and fixation offset effect (FOE), shown in the top left panel, is significant, but the interaction between IOR and target luminance, shown in the bottom left panel, is not. For manual responses, the interaction between IOR and FOE, shown in the top right panel is not significant, but the interaction between IOR and target luminance, shown in the bottom right panel, is significant.

is expressed when oculomotor responses are made to the target, and attention-based IOR is expressed when manual responses are made to the target.

What are the implications of these results? We propose that the recognition of at least two kinds of IOR—one that is motor based and expressed in eye movement responses, and one that is attention based and expressed in manual responses—may be an important step toward developing a comprehensive theory for the IOR phenomenon. A reasonable analogy is that significant progress was made in understanding visuospatial attention in the late 1970s, after it was recognized that there are two kinds of attention: one that is volitional and one that is reflexive (see Klein, Kingstone, & Pontefract, 1992; Posner, 1980). We are advocating for a similar notion here. It may be fruitful to examine IOR not as an effect that cuts across all response systems but rather as one that may be best understood within the context of the response system that is being used. In other words, we are proposing that motor-based IOR and attention-based IOR be studied as separable effects with potentially very different characteristics and underlying neural systems. Of course, understanding the interplay between these systems is also important, just as understanding the relation between reflexive and volitional attention has led to many new insights into human

attention and its neural underpinnings. As a first effort along these lines, we briefly consider saccadic (motor-based) IOR and manual (attention-based) IOR in isolation below.

Saccadic IOR and the Oculomotor Component

Saccadic IOR is a robust phenomenon that is typically measured with the fixation point remaining present in the display. Accordingly, we observed large and stable IOR in this condition, which was reduced when the fixation point was removed. Abrams and Dobkin (1994a), in contrast, observed little or no IOR when the fixation point remained on, which then reappeared when the fixation point was removed. As mentioned earlier, this pattern alone is reason to interpret Abrams and Dobkin's result with some caution, because they failed to observe IOR in a condition that typically generates large and robust IOR. Nonetheless, it is important to mention at this point that we replicated our pattern of results in a second experiment in which 14 new participants performed only the saccade task for four blocks of 64 trials. Using the same stimuli and procedures, we obtained a similar pattern as the present experiment, with an IOR of 50 ms when the fixation point remained on and 29 ms when the fixation point was removed, a

difference that was significant, $F(1, 13) = 5.98$, $p < .05$. We also replicated the lack of an interaction between IOR and target luminance in this experiment ($F < 1$).

In trying to determine the explanation for Abrams and Dobkin's (1994a) unusual pattern of results, it is worth noting that Abrams and Dobkin's methods were very different from the standard and simple cuing paradigm normally used to generate IOR. Abrams and Dobkin used a peripheral asterisk as a cue, and then the fixation stimulus turned from a circle to an asterisk that was identical to the peripheral cue and then back to a circle, and then the target, a circle, which was identical to the fixation circle, appeared either in the same location as the peripheral asterisk or in the opposite location. The potential for perceptual confusion in this experiment was substantial because the identity of the cue, fixation, and target overlapped within a single trial. If participants were using strategies to cope with the perceptually confusing display, it could produce idiosyncratic results (such as a failure to replicate IOR in a standard condition).[2]

We thus conclude that saccadic IOR does interact with the FOE but not in the direction reported by Abrams and Dobkin (1994a): The IOR effect is larger when the fixation point remains on the screen than when the fixation point is removed. The existence of this interaction supports the idea that IOR is generated at the level of the SC. A plausible objection to using an interaction between IOR and the FOE as a measure of an oculomotor component is that the FOE we observed could also have an attentional component. On the basis of the results, there are at least three reasons to believe the FOE observed in our experiments was specific to the oculomotor system. First, the FOE was no longer observed when manual responses were made to the target instead of saccades, consistent with it having a specifically oculomotor effect. Second, the FOE was additive with target luminance, replicating Reuter-Lorenz, Hughes, and Fendrich (1991), who took this as evidence that the FOE has a motor, rather than an attentional, effect. Finally, the interaction between FOE and IOR was not mediated by target luminance among the saccadic responses. This indicates that this specifically oculomotor process can influence IOR independent from any influence on attention. And why is IOR smaller when the fixation point is extinguished? We propose that this reduction occurs because disinhibition of the eye movement system caused by the removal of the fixation point also attenuates the inhibition that has built up to bias eye movements away from the previously attended location. This account suggests that these two kinds of inhibition, from the fixation point and from the cued location, share a common processing stage. This is consistent with IOR and the FOE being generated at the level of the SC.

Manual IOR and the Attentional Component

We looked for evidence of an attentional component in IOR by manipulating the luminance of the target stimulus. As noted earlier, there is strong evidence to support the assertion that IOR has an attentional locus, and a compelling example of this is the interaction between luminance and IOR, with IOR being larger when targets are dim (Reuter-Lorenz et al., 1996). This finding suggests that luminance effects and IOR occur at the same stage of processing, namely, the accumulation of information from the cued location (for similar use of this logic, see, e.g., Hawkins, Shafto, & Richardson, 1988; Hughes, 1984). When the target is

bright, the accrual of perceptual evidence of the target is very rapid, and attention can have little additional influence on target detection. When the target is dim and the accrual of target information is consequently slowed, effects of attention are more apparent. Our replication of the interaction between IOR and target luminance thus serves to increase confidence that IOR does indeed have an attentional component when it is measured using manual responses.

It is important to note that we did not observe this interaction when we measured IOR using saccades. We submit that this is because eye movements to a target onset were so rapid and reflexive that they undercut the opportunity for attention to have a measurable impact. More specifically, a subcortical structure such as the SC may have processed the target as well as programmed and executed a saccade before cortical brain processes responsible for attentional orienting are deployed. This account is consistent with the neurophysiology of the visual system in that the retino-tectal pathway, relaying through the SC, diverges from the more recently evolved pathway from the retina to the cortex via the lateral geniculate nucleus. It is our speculation that attention mediates incoming information within the latter pathway, but the older pathway is to some extent insensitive to the influence of covert attention. This is not to say that attention cannot influence eye movements, rather that eye movements do not necessarily await attention input to be executed. Thus, although IOR measured using manual responses reflects the locus of attention in the environment, IOR measured using eye movements may only reflect the process of overcoming the inhibition necessary to suppress an eye movement to the cue. This proposal is an important new addition to previous theories that suggested IOR has both perceptual and motor components. Our empirical dissociation between perceptual and motor effects supports the notion that not all responses are sensitive to the locus of attention. This notion is not without precedent. Klein (1980) also came to this conclusion when he observed an independence between eye movement preparation and shifts in spatial attention (see also Hunt & Kingstone, 2003; Klein & Pontefract, 1994).

Conclusion

We have found that both luminance and fixation offsets can influence IOR, demonstrating that IOR has both attentional and oculomotor components. We have further demonstrated that these

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[2] To explore this possibility, we attempted to replicate the Abrams and Dobkin (1994b) interaction between IOR and FOE, using the method described in their study. We ran two versions of this experiment: one in which the fixation condition was blocked, and one in which it was randomized (it was not clear from the Abrams and Dobkin method which procedure had been used). In both cases, we still produced robust IOR, but the interaction between IOR and FOE was not significant in either the random fixation condition, $F(2, 18) < 1$, or the blocked fixation condition, $F(1, 14) = 1.60$. The pattern of results that is most similar to the interaction obtained by Abrams and Dobkin occurs when the fixation offset condition was blocked, with IOR of 21 ms when the fixation point remained on, 26 ms when it was removed, and 35 ms when it was removed 200 ms before the target appeared. Of course, blocking the fixation condition increases the potential that strategic biases between conditions, rather than stimulus differences per se, would generate performance differences.

components can be isolated from each other. It appears that when the eyes remain stationary, IOR reflects a bias against allocating covert attention to the previously cued location. When the eyes are free to move to the target, IOR reflects a bias against executing a saccade to the cued location. We suggest that a fruitful direction for future investigation is to study each form of IOR—manual (attention-based) IOR and saccadic (motor-based) IOR—in isolation as well as in relation to one another. Recognition that there are two qualitatively different systems of IOR, attentional and motor, that divide along different response systems could lead to important new insights and theories of IOR, just as the recognition that there are two qualitatively different systems of attention, reflexive and volitional, led to important new insights and theories of attention.

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