

Inhibition of Return: Effects of Attentional Cuing on Eye Movement Latencies

Richard A. Abrams and Richard S. Dobkin

Inhibition of return refers to a bias against attending to and/or detecting visual stimuli at recently attended locations. In the present experiments, Ss were slower to initiate eye movements to previously attended locations. Furthermore, there was more inhibition when a peripheral (exogenous) flash signaled the target, compared with when a central (endogenous) arrow cue was used as an imperative stimulus. That pattern suggests that some of the inhibition is due to processes involved in detecting visual stimuli, and some of the inhibition is related to the movement of the eye. Subsequent experiments showed that the eye-movement component of the inhibition is not object-centered and does not move if the previously attended object moves, although the stimulus-detection component is object-centered. The results have implications for visual attention in general and for the link between overt and covert orienting.

As people move about, they almost continuously move their attention from one location to another. Overt movements of attention (eye movements) have been estimated to occur as many as 173,000 times each day (Robinson, 1981). Covert movements of attention may occur with each eye movement (Shepherd, Findlay, & Hockey, 1986) and without any eye movements at all (Posner, Nissen, & Ogden, 1978). Because both overt and covert movements of attention are thought to be important for people to interact successfully with their environment, considerable effort has been expended to understand the physiological, neurological, and psychological mechanisms that underlie them. This article continues in that spirit. We focus in particular on an attentional phenomenon known as inhibition of return.

Inhibition of Return

A movement of attention is typically accompanied by a facilitation in the processing of visual stimuli near the attended location (Eriksen & Yeh, 1985; Posner et al., 1978). If attention is then moved elsewhere, processing of stimuli at the previously attended location will actually be somewhat inhibited (compared to a location that has not been recently attended). This inhibition of a recently attended location has been termed inhibition of return (Posner, Rafal, Choate, & Vaughan, 1985), a term that refers to the relative difficulty in returning one's attention to

the previously attended location.¹ The inhibition appears to be uniquely related to location, as opposed to other stimulus attributes (Kwak & Egeth, 1992; but see Law, Pratt, & Abrams, 1994). It is observed even when the initial attentional cue is uninformative with respect to the location of the stimulus to be detected (Posner & Cohen, 1984).

Considerable research effort has been directed toward understanding the mechanisms underlying inhibition of return, because it is believed that they reveal important principles about the manner in which the visual system selects stimuli for processing. For example, it has been found that the presence and magnitude of the inhibition depends on the manner in which attention is initially directed to the target location. If attention is directed to a location by a peripheral flash at the location to be attended (i.e., exogenously), then the usual facilitation, and then later, inhibition of return is observed. However, if attention is directed by a central arrow cue (i.e., endogenously), then the attended location will not later be subjected to inhibition of return (Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989). This is true even though both arrow cues and peripheral flashes are effective in moving attention initially (see also Klein, Kingstone, & Pontefract, 1992).

A related result was reported by Rafal et al. (1989). They found that preparation to make an eye movement to a target location not only moved attention to that location initially, but also resulted in later inhibition at the target location. The inhibition of return was present regardless of whether an eye movement was actually produced—demonstrating that the

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¹ There is some disagreement regarding the conditions necessary to elicit inhibition of return. For simplicity, we characterize the inhibition as arising from an initial attentional movement. However, some results suggest that such a movement is not sufficient (e.g., Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989). Note also that it is not clear whether attention must be removed from the location that will later be inhibited (Maylor & Hockey, 1985). Our experiments do not depend on resolution of these issues.

preparation of an eye movement somehow engages the attentional system in a manner in which it is not engaged by a simple endogenous attention cue. Rafal et al.'s results suggest that a special link exists between movements of the eye and movements of attention, an issue that has been the subject of considerable research (e.g., Klein, 1980; Klein & Pontefract, *in press*; Posner et al., 1985; Shepherd et al., 1986).

We decided to examine more closely the link between inhibition of return and eye movements. Several researchers (Maylor & Hockey, 1985; Posner & Cohen, 1984) have suggested that inhibition of return helps to guide selection and orienting, which implies that it may have an especially close relation to eye movements. Others have explicitly shown that the inhibition does affect some aspects of eye movements (Maylor, 1985; Posner et al., 1985; Vaughan, 1984). In order to learn more about inhibition of return, we focused on the effects of the inhibition on eye movements.

Eye Movements and Inhibition of Return

Most prior studies of inhibition of return have involved the use of manual keypress responses (e.g., Rafal et al., 1989). However, a number of researchers have specifically examined the link between eye movements and inhibition of return. Vaughan (1984) and Maylor (1985) reported increased latencies for eye movements to previously attended locations. Posner et al. (1985) showed that the inhibition also decreases the likelihood that the subjects will move their eyes to a previously attended location. All of these results, however, could be due to either a reduced ability to detect a target at the previously attended location, or to a deficit limited specifically to the eye-movement system. If the former, then it would be expected that all responses (i.e., not only eye movements) to targets at previously attended locations would be slowed—and indeed, considerable evidence exists showing slower manual reaction times (RTs) to targets at previously attended locations (e.g., Maylor, 1985; Posner & Cohen, 1984; Rafal et al., 1989). Nevertheless, some results reported by Posner et al. (1985) and Maylor (1985) suggest that the inhibition does not simply reflect a decreased ability to detect the target at the previously attended location. They each presented targets at both cued and uncued locations and found that temporal order judgments were unaffected by whether the target location had been previously attended (although manual responses to the previously attended location were slowed). They concluded that the inhibition was specifically a response-related process, not a sensory one. This is because the sensory judgment (temporal order) was unaffected by the attentional manipulation, but the orienting response (eye movements or keypresses) was affected.

Despite these and other insights, it is still not clear whether eye-movement responses are inhibited by previous attentional orienting more than are non-eye-movement responses. In other words, is there something special about the inhibition of the eye movements? Existing data are equivocal, and we hope to provide at least a tentative resolution

of the issue. Although there is not strong evidence suggesting a special link between inhibition of return and eye movements, it is clear that eye movements are affected (e.g., Posner et al., 1985). There is evidence that eye movements in particular might be especially susceptible to the effects of inhibition of return. For example, as mentioned earlier, it has been suggested that inhibition of return serves to bias the nervous system from repeatedly sampling recently sampled locations. Thus, it might be especially important to prevent an eye movement to such a location—over and above the importance of inhibiting attention movements. One reason for this is that eye-movement production is fairly time consuming—saccade duration is on the order of 50 ms (Abrams, 1992; Abrams, Meyer, & Kornblum, 1989)—and there is a refractory period of approximately 200 ms, during which time another movement usually cannot be made (Hou & Fender, 1979). Given that, and the fact that movements of the eye are almost always accompanied by movements of attention (Shepherd et al., 1986), unnecessary eye movements could be very detrimental if efficient visual search is important. Inhibition of manual responses, however, would not be so important, because manual responses may not require movements of attention, and thus their occurrence would not have the same detrimental effect on the continuation of a visual search. Our experiments were designed to examine this possibility.

Overview of Experiments

Experiment 1 was designed to replicate the typical inhibition of return result with eye-movement latencies, similar to the studies reported by Vaughan (1984) and Maylor (1985). Experiments 2 through 4 were designed to learn more about the relation between eye movements and inhibition of return. In Experiment 2, we examined the extent to which the inhibition can be specifically attributed to motoric processes involved in making eye movements. In Experiments 3 and 4, we explored the extent to which the eye-movement component of the inhibition is encoded in object-based coordinates—a claim that has been made for inhibition of return in general (Tipper, Driver, & Weaver, 1991). Finally, in Experiment 5 we eliminated a potential alternative explanation for the pattern of results from Experiments 2–4.

In each of our experiments, the subject's attention was initially summoned to a peripheral location exogenously by a noninformative cue (i.e., a brief flash was presented in the periphery; Yantis & Jonides, 1984). We used an exogenous cue because it is known that such a stimulus is sufficient to produce inhibition of return (Rafal et al., 1989). Attention was then summoned back to the fovea through use of a transient visual stimulus. Unlike other researchers (e.g., Posner & Cohen, 1984; Rafal et al., 1989), we did not manipulate the conditions used to induce inhibition of return; rather, we were concerned with learning more about the nature and consequences of the inhibition itself. To do that, we manipulated other aspects of the display, including the nature of the imperative signal.

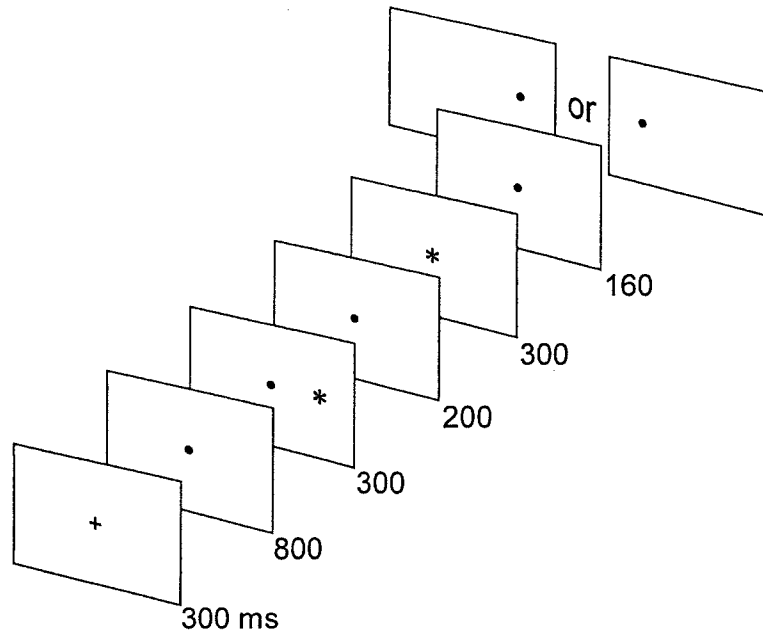


Figure 1. Sequence of events on a trial in Experiment 1. The numbers indicate the duration of each display (in milliseconds). See text for additional explanation.

Experiment 1

In this experiment, subjects were simply required to follow by eye (and as quickly as possible) a dot that jumped from a central fixation location to a peripheral location either to the left or right of center. The peripheral location either had or had not been recently attended. As others have shown, eye movements to recently attended (Maylor, 1985) or fixated (Vaughan, 1984) locations have longer latencies than those to other locations. We expected to also obtain that pattern here.

Method

Subjects. Eight undergraduates served as subjects in a single 1-hr session. They all had normal, uncorrected vision. Subjects were naive with respect to the purposes of the experiment. Each was paid \$5 for participation.

Apparatus and procedure. Testing was conducted in a dimly illuminated, sound-isolated room. Subjects were seated in front of a cathode-ray tube display, with their heads held steady by means of a dental impression plate. They wore a scleral-reflectance eye-movement monitor mounted on a spectacles frame (Applied Science Laboratories, Model 210). The sequence of events on a trial is shown in Figure 1. At the beginning of each trial, a plus sign was displayed at 0° (straight ahead) for 300 ms. The plus sign was then replaced by a dot, on which the subjects were required to fixate. An 800-ms interval transpired, after which a cue was presented 7° either to the right or left. The cue consisted of an asterisk that remained on the screen for 300 ms and was then removed. After 200 ms, another asterisk was presented at fixation for a duration of 300 ms; 160 ms after the removal of the asterisk at fixation, the dot at fixation jumped 7°, either to the left or right. The dot was equally likely to jump to either the previously cued or previously

uncued location. The subject's task was to look at the dot as soon as possible after it had jumped. The timing of cue and signal events was very similar to that used by Rafal et al. (1989). In particular, 960 ms elapsed between the onset of the initial peripheral cue and the displacement of the dot to the peripheral target location here, compared to a 950-ms interval in some of the conditions in Rafal et al.'s (1989) study.

Two aspects of the procedure should be emphasized. First, subjects were told to ignore the initial peripheral cue. Second, subjects were clearly informed that the location of the initial peripheral cue was unrelated to the subsequent target location.

Eye-movement monitoring. Samples of eye position were digitized and recorded at a rate of 1,000 points/s. The eye-movement monitor was calibrated at the beginning of each session by having the subjects fixate each of 11 evenly spaced points on the display. Subsequent eye positions were determined by linear interpolation of the digitized signal from the device. Calibration was confirmed at the beginning of each trial during the 800-ms period prior to presentation of the peripheral cue. During this time, subjects were supposed to be fixating upon the dot at 0°. If the output from the eye-movement monitor indicated that fixation was within 1.5° of the correct position, then the trial proceeded as described earlier. However, if the output was not within the specified range, the calibration procedure was automatically invoked, and the trial was repeated from the beginning.²

Eye position was also examined at two moments during the trial to ensure that subjects were not moving their eyes in response to the initial peripheral cue. A sample was saved from the eye-movement monitor (a) immediately after the offset of the cue (i.e., 300 ms after its onset), and (b) immediately before presentation of

² Note that failures to pass the fixation requirement are most likely due to movement of the spectacles on the subjects, or of the subjects relative to the display, and do not reflect inability or refusal of the subject to perform the task.

the central asterisk (i.e., 500 ms after the onset of the peripheral cue). The eye position during each of these samples was required to be within 3° of straight ahead; otherwise the trial was rejected. (When eye movements were made in response to the cue, they were almost always much larger than 3° in amplitude.)

To identify eye movements, we digitally filtered and differentiated the eye position signal to obtain a smooth record of velocity. An eye movement was defined to begin at the first moment in time at which the velocity exceeded 10°/s, subject to the constraint that the velocity remained above that value for at least 10 ms and subsequently exceeded 35°/s. These are the same criteria that we used previously (e.g., Abrams, Dobkin, & Helfrich, 1992).

Design. Each subject served in 10 blocks of 36 trials each. Half of the trials in each block involved target locations that had been cued earlier on that trial (and half of the trials had targets that were not cued). Cues and targets were equally likely to appear to the left or right.

Results

Table 1 shows the mean RTs on errorless trials for saccades to the left and right to locations that had either been cued or uncued. On the average, subjects were 21 ms slower to initiate saccades to the previously cued location as compared to the uncued location, $F(1, 7) = 25.8$, $p < .005$. Subjects were also 12-ms faster to initiate rightward saccades, $F(1, 7) = 5.6$, $p < .05$. Both rightward and leftward saccades were equally affected by the cue, $F(1, 7) < 1$. There was no difference in the number of trials discarded due to errors between the cued ($M = 7.7\%$) and uncued ($M = 6.7\%$) conditions, $t(7) = 2.15$, $p > .05$.

Discussion

The present results clearly show the effects of inhibition of return on eye movements. Subjects were slower to initiate eye movements to the location of an earlier cue, even though they were not required to respond at all to the cue. The results essentially replicate findings reported by Maylor (1985) and are similar to the results of Vaughan (1984) for eye-movement latencies.

Experiment 2

Having found a robust effect of inhibition of return on eye movements, we wanted to learn more about the nature of the inhibition. In particular, there are at least two general rea-

sons that eye movements may be slower to previously cued locations. First, it is possible that people are slower to detect the target stimulus when it appears at the inhibited location. This would be consistent with a relatively early, perhaps sensory locus of inhibition of return. We refer to this potential type of inhibition as inhibited stimulus detection. Second, it is possible that people are slower specifically at moving their eyes to the inhibited location. This would be consistent with a later, motoric locus of inhibition of return, and we refer to that as inhibited movement production. The present experiment was designed to assess the extent to which each of these possibilities contributed to the results of Experiment 1. To do that, subjects here also were required to look to a location that was either previously cued or uncued. On some trials the signal indicating which target to look to consisted of a peripheral flash (i.e., an exogenous signal), as it had in Experiment 1; on other trials the signal was a centrally presented arrow (i.e., an endogenous signal). Both types of trials had the same motoric requirements, because they both required subjects to look to either a previously cued or previously uncued location. However, only the former condition also required subjects to detect a peripheral stimulus.

Method

Subjects. Ten undergraduates who had not served previously served in the present experiment. They were unaware of the purposes of the experiment. Each was paid \$6 for participating in a 1-hr session.

Apparatus and procedure. This experiment was very similar to Experiment 1, with exceptions noted here. There were two types of trials: exogenous and endogenous. The sequence of events on exogenous trials was exactly as it had been on all trials in Experiment 1, with only one exception: Two small boxes (0.8° on each side) were added to the display here to serve as place holders: one centered 7° to the left of center, the other centered 7° to the right of center. The initial cue (asterisk) and the subsequent movement signal (dot) appeared inside one of the boxes. The boxes remained on the display throughout the trial. They were added to the exogenous condition because they were needed for the new condition (the endogenous condition). In the endogenous condition, the sequence of events was the same as in the exogenous condition with only one exception: At the end of the trial, instead of having the dot jump to the target location, the dot was simply replaced by an arrow that pointed either to the left or to the right. Subjects understood that this meant that they were to make an eye movement to the box that the arrow signaled. Thus, on both types of trials, subjects received a noninformative cue in the periphery, followed by a transient event at the center, and then a signal to move their eyes to a peripheral location. The only difference between the two conditions was the nature of the imperative signal.

Design. The single session contained 10 blocks of 32 trials each. Exogenous and endogenous trials were presented in alternate blocks. Within each block, half of the trials were to the cued location, which was equally often to the left and right. Half of the subjects began with a block in the exogenous condition.

Results

Figure 2 shows the mean latencies in each condition. As can be seen, subjects were slower to look to cued locations

Table 1
Mean Latencies (in Milliseconds) to Initiate Eye Movements as a Function of Cuing and Direction (Experiment 1)

Condition	Direction		<i>M</i>
	Left	Right	
Cued	231.6	220.3	226.0
Uncued	212.0	198.2	205.1
<i>M</i>	221.8	209.2	—

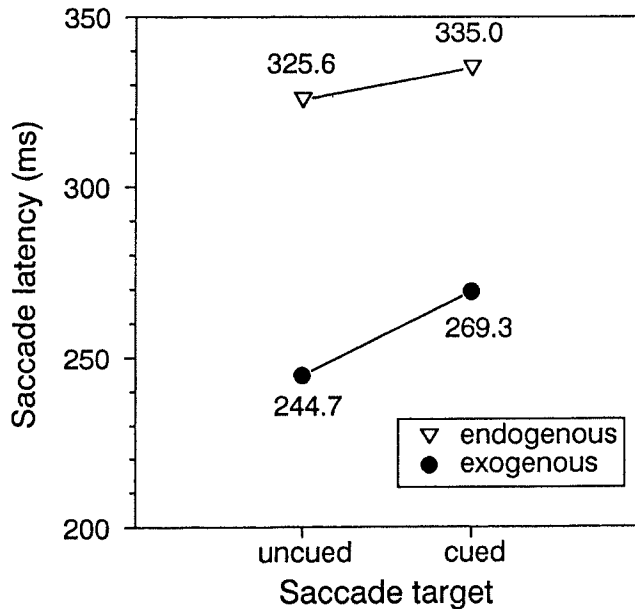


Figure 2. Mean saccade latencies from Experiment 2 as a function of the nature of the cue and signal.

compared to uncued locations overall, showing the usual inhibition of return effect, $F(1, 9) = 21.8, p < .005$. Most important, the inhibition of return effect (i.e., effect of cue type) was smaller in the endogenous condition ($M = 9.4$ ms) than in the exogenous condition ($M = 24.6$ ms), $F(1, 9) = 6.7, p < .05$. Also, latencies in the endogenous condition were considerably slower than in the exogenous condition, $F(1, 9) = 35.5, p < .001$. There were no differences in the error rates as a function of endogenous or exogenous target condition, $F(1, 9) < 1$, or cuing, $F(1, 9) < 1$, nor was there an interaction, $F(1, 9) = 2.8, p > .10$. Finally, the 9.4 ms of inhibition in the endogenous condition was reliably greater than zero, $t(9) = 3.8, p < .005$.

Discussion

In the present experiment, subjects were slower to look to a previously attended location (relative to an unattended location) when the signal indicating the required response was exogenous (a dot appearing at the target location) and when it was endogenous (a central arrow). Our interpretation of this is that at least some of the inhibition specifically affected the response, in this case an eye movement, and the inhibition effect is not limited to processes involved in detecting the stimulus. This is because, in the endogenous condition, eye movements to the previously attended location were slowed, even though subjects were not required to detect any peripheral stimuli at that location. In the exogenous condition, however, it was necessary for subjects to detect a stimulus at the previously attended location, in addition to the requirement to produce an eye movement to that location (on "cued" trials). There, the inhibition effect was more than twice as large as in the endogenous condi-

tion, suggesting that an additional inhibitory component is involved on those trials. In particular, it appears to be more difficult to detect a stimulus at the previously attended location—over and above the difficulty in moving one's eyes there. We think these results suggest that the inhibition affects at least two different types of processes: (a) those involved in detecting visual stimuli, and (b) those involved in producing eye movements. The next experiment was designed to learn more about the eye-movement-related inhibition.

Experiment 3

Having identified a component of inhibition of return related to eye movements, we sought to learn more about its properties. In particular, a recent report by Tipper et al. (1991) showed that inhibition of return is object centered. That is, if a previously attended object moves, the inhibition will move with the object. That result, however, was obtained with manual responses and exogenous target stimuli. Thus, it is relevant only to the component of the inhibition that affects stimulus detection, and may not reflect properties of the inhibitory component that affects eye movements. The present experiment was designed to determine whether the eye-movement-related component of inhibition of return is also object centered. To accomplish that, we had subjects make eye movements to objects that moved to new locations after they had either been previously cued or uncued. The signal indicating which object to look to was a central (endogenous) arrow.

Method

Subjects. Fifteen undergraduates, naive with respect to the purposes of the experiment, each served in one 1-hr session in exchange for a payment of \$6. None had served previously.

Apparatus and procedure. The apparatus was the same as that used in Experiments 1 and 2. The sequence of events on a trial was the same as that in the endogenous condition of Experiment 2, except that the boxes here initially began above and below fixation, and then rotated into a horizontal orientation during the trial. These events are illustrated in Figure 3. An asterisk was presented in one of the boxes above and below fixation for 300 ms. A 200-ms period transpired, after which an asterisk was presented at the fixation location for 300 ms and the boxes smoothly moved 90° in a clockwise direction into a horizontal orientation. The motion was accomplished by displaying boxes at each of 15 equally spaced angular positions between the vertical and horizontal orientations, each for 20 ms. The remainder of the trial proceeded as in Experiment 2. Specifically, the asterisk disappeared and was replaced by a dot for 150 ms. The dot was then replaced by an arrow that indicated that subjects were to look at one of the boxes to the left or right of fixation.

After testing 7 subjects under the conditions described above, we wondered whether the rotation of the boxes was so salient that it may have prevented subjects from fully appreciating the reappearance of the asterisk at the center of the display. (In particular, we suspected that the box movement may have reduced the likelihood that the transient onset of the central asterisk would capture the subjects' attention.) To eliminate that possibility, for the remaining eight subjects we flashed the asterisk off and then on again once

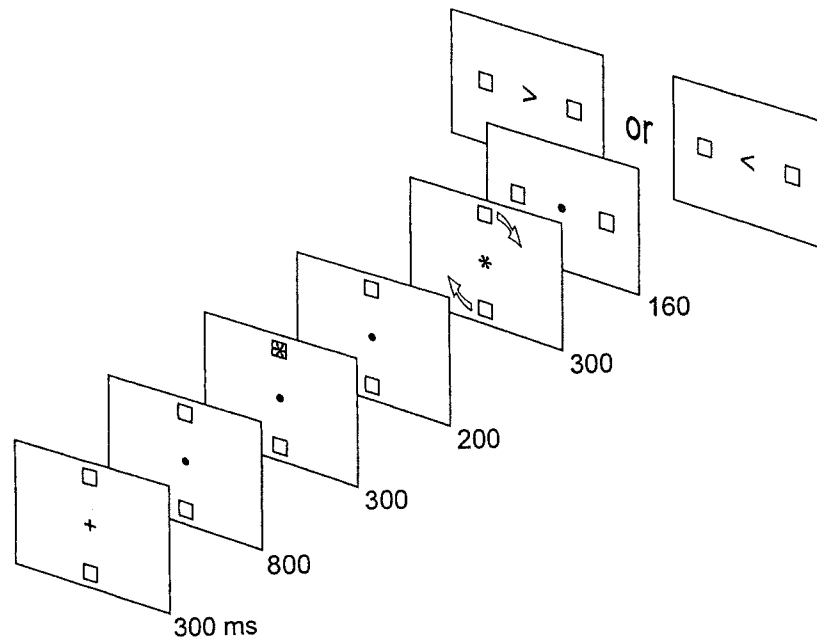


Figure 3. Sequence of events on a trial in Experiment 3. The numbers indicate the duration of each display (in milliseconds). The arrows in the fifth frame indicate motion of the boxes and were not present on the display. See text for additional explanation.

during the rotation of the boxes. This change ultimately did not affect the results at all, and we report all results for both groups combined.

Design. Each subject served in a practice block of eight trials that was not analyzed, followed by 8 test blocks consisting of 32 trials each. The target on a trial was 50% likely to be the box that had been cued (recall that the cues were presented when the boxes were vertically oriented) and that was equally often to the right or left.

Results

Mean RTs to cued and uncued boxes are shown in the open symbols of Figure 4. As can be seen, subjects were slightly faster to look to the previously cued box compared to the uncued box (mean difference = 2.5 ms), $F(1, 14) = 5.12$, $p < .05$. This difference occurred although at the time of the response, the cued and uncued boxes were equidistant from the location at which the cue had been presented. The direction of the response did not affect latency, nor did it interact with cuing, $F_s(1, 14) < 1$. There were no differences in the error rates between the two conditions, $t(14) = .28$, *ns*.

Discussion

In contrast to the report of Tipper et al. (1991), we did not find evidence for object-centered inhibition of return. Instead, subjects here were actually slightly faster to look to the previously cued object, suggesting that some facilitation moved with the object to its new location. We attribute the different pattern of results to an important difference in the

stimuli: In the Tipper et al. (1991) experiment, the RT was a measure of the time needed to detect a peripheral stimulus, and subjects were slower if the stimulus was presented in a previously attended object. In the present experiment, however, subjects were required only to look at either a previ-

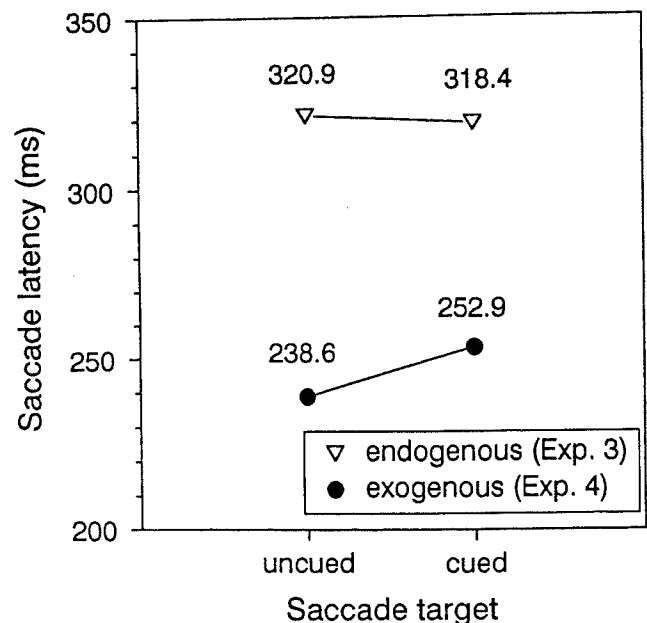


Figure 4. Mean saccade latencies from Experiment 3 (open symbols) and Experiment 4 (filled symbols). Exp. = Experiment.

ously attended or unattended object (a central arrow indicated which object to look at). Thus, Tipper et al.'s study probably reflects the operation of the mechanisms involved in detecting visual stimuli, and our study addresses mechanisms involved in making eye movements. The conclusion is that the eye-movement-related component of inhibition of return is not object centered.

Experiment 4

Before continuing our discussion, there is an alternate explanation of the results from the previous experiment that should be considered. It is possible that we failed to find object-centered movement of the inhibition because of some fundamental flaw in our method that prevented us from detecting it, and not because of the unique requirements of our task, as we argued. To eliminate that possibility, we conducted the present experiment using conditions designed to replicate the original Tipper et al. (1991) result. In particular, subjects here had to move their eyes to a horizontally aligned box that either had or had not been cued when it was aligned vertically. However, in the present experiment, we signaled the required response by presenting a peripheral stimulus in the box to which to move. Thus, subjects here not only had to produce an eye movement to the object, but they were also required to detect a stimulus in that object. If the stimulus-detection component of inhibition of return is indeed object centered, then eye movements to previously cued objects should be inhibited if the signal is an exogenous one like the one used here.

Method

Subjects. Eight experimentally naive undergraduates who had not served previously participated in a 1-hr session. Each was paid \$6.

Apparatus, procedure, and design. This experiment was identical to Experiment 3 with one exception: Instead of an arrow signaling which box to look to, the dot at fixation jumped into one of the boxes. The subjects' task was to follow the dot by eye.

Results

Mean latencies to look to cued or uncued boxes are shown in the solid circles of Figure 4. As can be seen, subjects were considerably slower to initiate eye movements to the previously cued box (mean difference = 14.4 ms), even though at the time of the response the cued and uncued boxes were equidistant from the location at which the cue had been presented, $F(1, 7) = 13.2, p < .01$. Movements to the right were somewhat faster than those to the left, $F(1, 7) = 6.8, p < .05$, but direction did not interact with cuing, $F(1, 7) < 1$. An equal number of errors occurred in the two conditions, $t(7) = .33, ns$.

We also compared the results of Experiments 3 and 4. There was an overall effect of cuing, with latencies slightly slower to previously cued objects, $F(1, 21) = 12.5, p < .005$. However, the effects of cuing interacted with experiment, indicating that the inhibition that was present in Experiment

4 was not present in Experiment 3, $F(1, 21) = 25.7, p < .0005$. Latencies were also significantly faster overall in Experiment 4 than in Experiment 3, as a result of the nature of the stimuli (endogenous in Experiment 3, exogenous in Experiment 4), $F(1, 21) = 28.5, p < .0001$.

Discussion

In the present experiment, subjects were required to detect a stimulus in, and then to make an eye movement to, an object that either had or had not been previously attended. When the imperative stimulus was presented, both objects were equidistant from the location at which the attentional cue had been presented. Subjects were slower to initiate the eye movement to the previously attended object, indicating that inhibition of return does indeed move with an object when the object moves, as Tipper et al. (1991) showed.

Experiment 5

There is an alternate explanation for the difference in inhibition observed between endogenous and exogenous stimuli in Experiment 2, and between Experiment 3 (which included only endogenous stimuli) and Experiment 4 (which included only exogenous stimuli). Consider the results from Experiment 2 (Figure 2): Considerably less inhibition was present for endogenous stimuli than for exogenous stimuli; however, latencies to endogenous stimuli were also much longer. Because inhibition of return must dissipate with the passage of time, it is possible that there was simply less inhibition present by the time subjects produced their responses in the endogenous conditions. That could explain the reduced magnitude of inhibition without appealing to a dual-process mechanism like the one we proposed. Exactly the same argument could also be made for the difference observed between Experiments 3 and 4 (Figure 4). To address this potential limitation, we conducted the present experiment. This experiment was identical to Experiment 2 except that stimulus presentation was delayed somewhat in the exogenous condition to equate more closely the time between the initial attentional cue, and the onset of the response in the endogenous and exogenous conditions. If the differences reported earlier are due to differences in the amount of inhibition of return that was available, then there should be an equal amount of inhibition of return here for the endogenous and exogenous conditions.

Method

Subjects. Sixteen experimentally naive undergraduates who had not served previously each participated in one 1-hr session. Each was paid \$6.

Apparatus, procedure, and design. This experiment was identical to Experiment 2 with only one exception: An additional 80-ms delay was inserted prior to the appearance of the target in the exogenous condition. (In other words, the display that was presented for 160 ms immediately prior to stimulus presentation in Experiment 2 was presented for 240 ms in the exogenous condition of the present experiment.) No additional delay was added to the

endogenous condition. Eighty milliseconds was chosen because it closely matched the mean difference between endogenous and exogenous trials in Experiment 2 (73.3 ms) and the mean difference between Experiments 3 and 4 (73.6 ms).

Results

Mean latencies to look to cued and uncued locations are shown in Figure 5, with latencies measured from the onset of the imperative stimulus (an arrow in the endogenous condition and the displacement of the fixation dot in the exogenous condition). As can be seen, latencies in the endogenous condition were considerably longer than in the exogenous condition, $F(1, 15) = 198.8, p < .0001$; mean difference = 93.6 ms. Recall, however, that the exogenous stimuli were delayed by 80 ms relative to endogenous stimuli. Thus, responses in the endogenous condition were made at approximately the same time relative to the initial attentional cues at the beginning of the trial, compared to responses in the exogenous condition (i.e., the 93.6-ms difference in latencies between endogenous and exogenous conditions was not significantly different from the 80-ms advantage given to the endogenous stimuli; $t[15] = 2.05, p > .05$).

Latencies to cued locations were also longer overall, showing the usual inhibition of return effect, $F(1, 15) = 17.1, p < .005$. Most important, the inhibition of return effect was greater in the exogenous condition than in the endogenous condition, $F(1, 15) = 5.1, p < .05$. This was true even though responses in exogenous and endogenous conditions were initiated at essentially the same time.

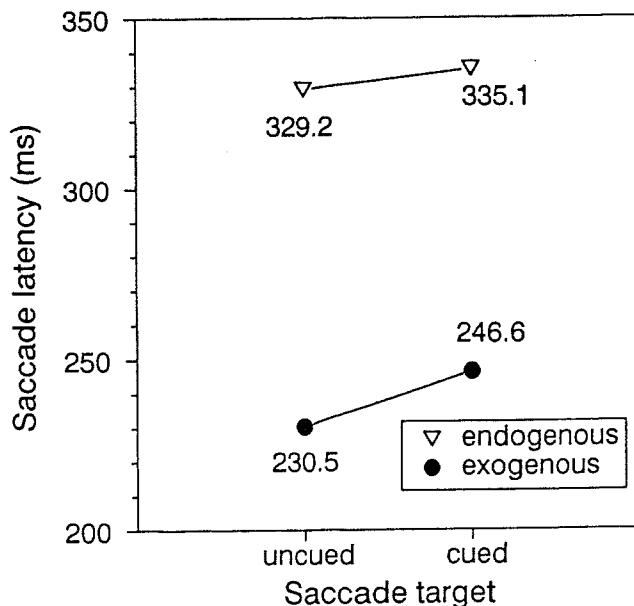


Figure 5. Mean saccade latencies from Experiment 5 as a function of the nature of the cue and signal. Latencies were measured from stimulus onset. To compare latencies relative to the initial attentional cue, an additional 80 ms should be added to latencies in the exogenous condition.

Discussion

The present experiment serves to eliminate an alternative interpretation of our earlier results. According to the alternative, endogenous conditions may have been less influenced by inhibition of return than exogenous conditions simply because endogenous responses are usually initiated later than exogenous responses, allowing a greater opportunity for the inhibition to decay. However, the present experiment shows that such a phenomenon cannot explain the entire pattern of results, because we still find greater inhibition of return for exogenous stimuli, even when the times of response onset are equated.

General Discussion

In this article we presented evidence that inhibition of return consists of two distinct components: a stimulus-detection component, which should affect all responses, and a movement-production component, which might be unique to the oculomotor system. Experiments 1 and 2 showed that people are slower to move their eyes to a previously attended location. Experiment 2 showed that such a result could not be attributed entirely to the difficulty of detecting a stimulus at the inhibited location, because some inhibition is present even if no peripheral stimulus detection is required (i.e., the endogenous condition of Experiment 2). Such inhibition indicates the presence of the movement-related component. Because most, if not all, previous studies of inhibition of return have used exogenous imperative stimuli, the movement-related component of inhibition has remained undiscovered until now. Experiments 3 and 4 showed that the stimulus detection component of the inhibition will move when the previously attended object moves (Experiment 4) but the movement-related (i.e., oculomotor) component does not move (Experiment 3), suggesting that the two components are fundamentally different. Experiment 5 ruled out an alternate explanation for the results of the earlier experiments.

Relation to Eye-Movement Mechanisms

Perhaps one of the most important implications of the present results involves the relation between the mental mechanisms responsible for controlling movements of the eyes (overt orienting) and those responsible for controlling movements of attention (covert orienting). Our results suggest that there are some close links between the two systems, although the link is somewhat different from one that has been suggested by others (e.g., Rizzolatti, Riggio, Dascolo, & Umiltà, 1987). We have shown that the eye-movement system can be influenced by prior movements of attention. That is, our initial exogenous attentional cue subsequently produced inhibition in the eye-movement system. This is related to the results of Rafal et al. (1989), who found that eye-movement preparation influenced the attention system (i.e., inhibition of return), whereas we found an influence of attention on eye movements. Despite these

apparent links between overt and covert orienting, other evidence argues against the possibility that eye movements and attention movements are controlled by a single mechanism (e.g., Klein, 1980; Klein & Pontefract, in press; Reuter-Lorenz & Fendrich, 1992).

Different Spatial Maps for Eye Movements and Attention

Certain aspects of our results are also not consistent with the hypothesis that eye movements and attention movements are controlled by the same mechanism. In particular, when a previously attended object moved, stimulus detection was inhibited at the object's new location, but eye movements to that location were not inhibited (Experiments 3 and 4). Thus, the attention system and the eye-movement system appear to be guided by different representations of space. One important consequence of the existence of distinct spatial maps is that "motor readiness" explanations of inhibition of return seem very unlikely, or at least incomplete. For example, Tassinari, Aglioti, Chelazzi, Marzi, and Berlucchi (1987) suggested that inhibition of return is due to activity in the motor system that is necessary to inhibit overt orienting toward the initial attentional cue. The inhibition presumably persists long enough to influence subsequent target detection.³ However, if inhibition of return is due to inhibited motor output, then one might not expect the inhibition to move when the cued object moves, contrary to the findings of Tipper et al. (1991) and Experiment 4. This is because inhibited movements are likely to be encoded in terms of spatial location and not object identity. Furthermore, even if one assumed the existence of an object-centered mechanism for the inhibited motor output, then all of the inhibition of return would be expected to be object centered. However, as we have shown (Experiments 3 and 4), only the stimulus-detection component appears to be object centered. Thus, the motor readiness explanation of Tassinari et al. (1987) is, at best, an incomplete account of the mechanisms underlying inhibition of return.

Limitations of Present Conclusions

There are, of course, a number of limitations of the present study. Our results are somewhat difficult to reconcile with some earlier work on inhibition of return. Recall that Posner et al. (1985) and Maylor (1985) showed that judgments of the temporal order of stimuli presented at previously cued and uncued locations did not depend on the presence of inhibition of return. That is, subjects were in a state such that responses to cued targets would be slowed, but sensory judgments about the same targets were not impaired. The interpretation of that pattern was that inhibition of return produces a bias against responding to a particular stimulus, but not in detecting the stimulus. However, in the present article we have argued for the existence of an inhibitory component involved exclusively in the detection of an object at the inhibited location, over and above inhibitory influences that affect the response that

subjects produced. It is difficult to imagine an impairment that affects stimulus detection but does not affect temporal order judgments. The key may be that subjects typically need not produce a speeded response in temporal-order conditions, but must do so in orienting and RT conditions, such as those used in the present experiments.

It is also important to note that our conclusions may not necessarily apply to the type of inhibition of return induced by the procedures of Rafal et al. (1989). Recall that their subjects first prepared, but then sometimes canceled, an eye movement. Subjects subsequently experienced inhibition of return for the intended saccade target. We do not know if inhibition of return produced in that manner has the same properties (and includes all components) as inhibition produced using exogenous flashes, as in the present article. Indeed, because Rafal et al. (1989) obtained inhibition of return using manual keypress responses, it would seem that their effect must include at least the detection component that we have identified. A complete answer will require new experiments.

It should also be noted that we have not yet examined one key feature of the eye-movement component of inhibition of return. In particular, because that component appears not to be object centered (Experiment 3), it may be environmentally based. That is, people might be inhibited in making eye movements to a previously cued location (in response to endogenous signals), even if the cued object has moved away from that location. One way to examine that possibility would involve object motion like that used in Experiments 3 and 4, but with responses sometimes required to the original locations of the objects. Tipper, Weaver, Jerreat, and Burak (1994) performed such a manipulation, although without eye-movement responses. If the eye-movement-related inhibition does indeed remain at the originally cued location, that would provide additional support for our proposed distinction between the two types of inhibition.⁴

Estimates of Inhibition Magnitudes

It is possible to derive estimates of the magnitudes of the two inhibitory components, at least in the context of the present experiments. We claimed earlier that the inhibition in the exogenous condition of Experiment 2 includes contributions from both the stimulus detection and movement production components, whereas the endogenous condition of that experiment includes only the latter type of inhibition. Thus, subtracting the endogenous effect size (9.4 ms of inhibition) from the exogenous (24.6 ms) should yield an estimate of the stimulus-detection component. The estimate derived in that manner is 15.2 ms. A similar estimate from Experiment 5 yields a value of 10.3 ms; averaging the two estimates yields a magnitude of 12.8 ms. Recall also that the

³ However, this does not explain why Vaughan (1984) found inhibition of return even when subjects were permitted to move their eyes to the location of the initial cue (see also Maylor & Hockey, 1985).

⁴ We thank Steve Tipper and two anonymous reviewers for suggesting these possibilities.

combined results of Experiment 3 and Experiment 4 caused us to conclude that the inhibition in Experiment 4 includes only the stimulus-detection component. That effect was 14.4 ms in magnitude, very similar to the 12.8-ms estimate derived above. The close correspondence of the two estimates helps to strengthen our general conclusions.

Locus of Inhibition

Finally, we may be able to speculate somewhat regarding the supposed locus of the inhibition of return effects. Given that different spatial maps appear to underlie the two components, it seems likely that they exert their effects at different places in the visual and oculomotor systems. The finding that the eye-movement-related component appears to not be object centered may provide some insight. It may be that the movement-related inhibition operates at a level of the oculomotor system in which eye movements are encoded in terms of the desired spatial location (e.g., Mays & Sparks, 1980), or in terms of the direction and amplitude of the required movement (e.g., Abrams & Jonides, 1988). Such encoding is believed to occur in the superior colliculus (Sparks & Mays, 1990). Inhibition at that late stage of eye-movement preparation might not be expected to be object centered. Interestingly, it has also been suggested that the stimulus-detection component might also be mediated by the colliculus (Posner et al., 1985; see also Tipper et al., 1991). Indeed, some evidence shows that the superior colliculus receives visual input, in addition to its known role in producing eye movements (see Jay & Sparks, 1990). Thus, it is entirely possible that both types of inhibition could be mediated by mechanisms there (but see Tipper et al., 1994). Of course, definitive answers to these questions will have to await further research.

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