

Inhibition of Return to Successively Cued Spatial Locations

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Inhibition of return refers to a bias against returning attention to a location that has been recently attended. Experiments are reported that examined inhibition of return to multiple exogenously cued spatial locations. When 2 peripheral locations were cued in succession, inhibition was found for only the 1 most recently cued location. In addition, more inhibition occurred at the location of the most recent cue if the earlier cue had also been presented there, as compared with an earlier cue at a different location. Thus, the magnitude of the inhibition for a location appears to depend on the effectiveness of the attentional cue to that location. Other results suggest that candidate locations for inhibition are displaced by subsequent cues—they do not simply decay. The results provide an initial framework within which to study inhibition of return to multiple spatial locations.

During everyday life, people must often locate visible objects. Tasks such as finding the pen on one's clean desktop, meeting a friend at a quiet street corner, or finding one's car in an otherwise empty parking lot can all be accomplished relatively easily. However, considerable difficulty might be encountered when the desk is cluttered, the street corner is busy, or the lot is filled with other cars. In those situations, it may be necessary to move one's attention from location to location to find the target object. Such searches are often accomplished by making eye or head movements, although many searches must also involve covert movements of attention—without any eye or head movements. Visual searches such as these (either overt or covert) would obviously benefit from a mechanism that prevented one from re-searching a previously inspected location. Indeed, such a mechanism has been identified and has been termed *inhibition of return*, referring to the fact that attention is sometimes inhibited in returning to a previously attended (i.e., inspected) location (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985).¹

Inhibition of Return

Considerable research has recently been conducted to more fully understand inhibition of return and the underlying mechanisms. Researchers have found that the inhibition occurs for previously attended spatial locations (Posner & Cohen, 1984), for previously attended objects that have moved to new locations (Tipper, Driver, & Weaver, 1991),

and for previously attended colors (Law, Pratt, & Abrams, 1995; but see Kwak & Egeth, 1992). Inhibition of return affects manual responses (Maylor & Hockey, 1987; Rafal, Calabresi, Brennan, & Sciolto, 1989) and eye movements (Abrams & Dobkin, 1994a, 1994b; Maylor, 1985; Vaughan, 1984). Also, the manner in which attention is cued can have a dramatic effect on the amount of inhibition (Posner & Cohen, 1984; Rafal et al., 1989). Despite the wealth of research, many questions concerning inhibition of return remain unanswered. For example, most prior studies have examined inhibition of return to only the most recently attended location (or object; e.g., Abrams & Dobkin, 1994b; Posner & Cohen, 1984; Tipper et al., 1991; Tipper, Weaver, Jerreat, & Burak, 1994). However, in complex real-world environments, a great many movements of attention might be required before a search is terminated. An important question about such a search is as follows: To how many previously attended locations will the return of attention be inhibited? This question was the focus of the present study.

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¹ It is worth noting that there is some uncertainty about the extent to which inhibition of return is really an attentional phenomenon (see Reuter-Lorenz, Jha, & Rosenquist, in press). The uncertainty is due in part to some results of Posner and Cohen (1984). They argued that if inhibition of return is a consequence of prior attentional orienting, then inhibition should exist at a location only after prior facilitation at that location. By simultaneously cuing two target locations, Posner and Cohen found inhibition that had not been preceded by facilitation, thus arguing against an attentional explanation. However, using the same simultaneous-cuing paradigm, Maylor and Hockey (1985) found both facilitatory and inhibitory effects. It is not presently clear how to resolve this discrepancy. Such resolution may ultimately hinge on the very definition of attention. Fortunately, resolution was not necessary for the present purposes, because it is clear the inhibition of return is closely related to the attentional system. Thus, our inquiry into properties of inhibition of return proceeded, with a precise definition of it postponed until more data become available.

Inhibition to Multiple Locations

If indeed inhibition of return assists visual search by biasing people toward fresh sources of input (e.g., Posner & Cohen, 1984; Tipper et al., 1994), then it may be advantageous for inhibition to operate for more than one spatial location. For example, consider the task of looking for a nonmoving target item in a finite number of possible locations. The fastest search would obviously be one in which attention (i.e., the search) never returned to a previously inspected location. However, it is reasonable to expect that there also may be some cost involved in maintaining memory of the previously inspected locations. If the number of searched locations was very large, the cost of maintaining the memory might exceed the benefits of the inhibition.

Few studies have examined whether inhibition of return occurs for more than one previously attended location. Klein (1988) found inhibition at several previously searched locations. However, Klein's multiple stimuli were presented simultaneously, and the participants did not attend to the various locations in any specific order. In addition, Wolfe and Pokorny (1990) presented evidence that the slower responses to the previously attended locations in Klein's experiment might have been due to forward masking and not inhibition of return.

Maylor and Hockey (1987) also studied inhibition to multiple spatial locations. In their study, participants responded to the onset of a peripheral target on each trial following an uninformative exogenous cue. Participants were slower to detect targets at the cued location, consistent with the typical inhibition-of-return effect. Interestingly, participants were also slower to detect targets that were at the location of the target from the previous trial, regardless of the location of the most recent cue. Presumably, the previous target also served as an attentional cue. This finding suggests that inhibition of return may indeed exist for more than one recently attended location, as Maylor and Hockey suggested. However, because participants responded to each target, it is unclear how much of the effect was due to covert orienting to the previous target and how much should have been attributed to the production of an overt response. Indeed, inspection of their data revealed that the effect of prior target location was greater than that of present cue location, consistent with a unique role of response production. The present study was designed to examine inhibition of return by successively cuing attention to multiple locations before presentation of an imperative target stimulus.

Examining inhibition of return to multiple locations may also provide some insight into how recently attended locations become uninhibited. It is known that inhibition of return does decay over time (Vaughan, 1984); thus, inhibition may occur only at the locations attended within a given time period. In addition to decay, there may also be a limit to the number of previously attended locations that can be retained in memory.² If so, then newly attended locations may displace older previously attended locations even before the inhibition has had time to decay. It is also possible that decay and displacement may interact such that the rate

of decay depends on the number of to-be-inhibited locations. The present experiments examined these and other aspects of inhibition of return to more than one spatial location.

Overview of Present Approach

To study this question, we used a modified version of a paradigm that has been used by us and others in the past to study other questions about inhibition of return (e.g., Abrams & Dobkin, 1994b; Rafal et al., 1989). The technique involves exogenous cuing; that is, the participant's attention is summoned to each to-be-attended location through a transient visual event. The use of exogenous cuing makes our study more comparable to previous work on inhibition of return but does limit the conclusions that we may be able to make about visual search. This is because visual search is typically thought to involve more centrally directed (i.e., endogenous) movements of attention. Indeed, there are a number of known differences between endogenous and exogenous orienting that may limit the conclusions that we can draw about endogenous visual search (Klein, 1980; Klein & Pontefract, 1994; Reuter-Lorenz & Fendrich, 1992). Perhaps most important, it has been shown that endogenous covert orienting does not yield inhibition of return (Posner & Cohen, 1984; Rafal et al., 1989). Thus, to study inhibition of return, one must use exogenous cuing. Nevertheless, our results are still relevant to externally triggered visual searches in which one must find a suddenly appearing target among a large number of distractors. Such searches may occur when one is trying to detect a new blip on a radar screen or a loose puck among a group of hockey players.

Experiment 1

Experiment 1 was designed to ascertain if inhibition of return would be found for more than one previously attended location. A condition in which two different target locations were cued in succession was compared with a condition in which one target location was cued twice. Participants then detected a target that was presented at the first cued, the second cued, or the uncued location. The results showed whether inhibition of return affected more than a single location.³

Method

Participants. Ten students from Washington University participated in a single 1-hr session. All of the participants had normal uncorrected vision, and none had any prior knowledge of

² By "memory," we simply mean whatever mechanism is used for the purpose of maintaining inhibition to return attention to previously attended locations.

³ Because our paradigm involved static peripheral objects, we could not distinguish between location-based and object-based inhibition of return (see Tipper et al., 1994). For convenience, we referred to the inhibition found in the present experiments as occurring at locations.

the purposes of the experiment. Each student was paid \$6 for participating.

Apparatus and procedure. The experiment was conducted in a soundproof dimly illuminated booth. Participants were seated in front of a computer monitor, with their heads held steady by a bite bar made of dental impression compound. Participants wore a spectacle frame fitted with a scleral-reflectance eye movement monitor (Model 210, Applied Science Laboratories, Bedford, MA). A computer keyboard was placed directly in front of them so that they could easily press any of the keys.

The sequence of events on each trial is shown in Figure 1. To start each trial, a plus sign (+) was displayed in the center of the monitor (0° of visual angle) for 300 ms. On each side of the plus sign was a box (0.8° on each side, centered 7° to the right and left of the plus sign). Then, the plus sign was replaced by a dot, on which the participants were required to fixate. Participants fixated on the dot for 800 ms. Following the fixation interval, a cue was presented either at the fixation dot or in one of the boxes, and it served to summon the participants' attention (Yantis & Jonides, 1984). We called this the *first cue*. The cue was an asterisk (*) that appeared on the screen for 200 ms and then was removed. One hundred and sixty ms after the first cue was removed, a *second cue* was presented in exactly the same manner as was the first cue (at fixation, left box, or right box). One hundred and sixty ms after the removal of the second cue, another asterisk was presented at fixation for 200 ms (the *fixation cue*). One hundred and sixty ms after the removal of the fixation cue, the dot at fixation jumped into either the right or the left box. The dot was equally likely to jump to the left or to the right. As soon as the participants saw the dot jump, they were instructed to press the appropriate key on the keyboard as quickly as possible: If the dot jumped to the left, they were to press the "Z" key; if the dot jumped to the right, they were to press the "F" key.

The participants' eye positions were monitored three times during the trial to ensure that their eyes did not leave the fixation dot during the presentation of the cues. The first monitoring point occurred at the start of trial. To initiate each new trial, the participants had to be fixated on the fixation dot. The second monitoring point was immediately after the offset of the second cue, and the third monitoring point was immediately before the presentation of the final central cue. If the eye position at either of these two monitoring points was more than 3° from fixation, the trial was discarded.⁴ Note that the reaction times (RTs) measured were from the choice manual keypress responses. Participants were clearly instructed to respond only to the jump of the fixation dot to the right or the left. The participants were also informed that the fixation dot was equally likely to jump to the left or the right on every trial regardless of the location of the cues.

Design. The single session consisted of 10 blocks of 32 trials each. We used two cuing sequences in Experiment 1, an opposite-side sequence and a same-side sequence. Examples of both sequences are shown in Figure 1. The *opposite-side* sequence consisted of an initial cued target location (i.e., one of the boxes), followed by a cue to the opposite target location, which was then followed by a cue at the fixation location. The *same-side* sequence consisted of an initial cued target location, followed by a cue to the same target location, which was then followed by a cue to the fixation location. For purposes of the analysis, the location that was first cued in the opposite-side sequence was considered the *uncued* location, whereas the location that was cued second was considered the *cued* location. For the same-side sequence, the location that was cued twice was considered the cued location, and the location that was never cued was considered the uncued location. Thus, there were four conditions overall (opposite-side

cued and uncued, and same-side cued and uncued). These conditions were randomly presented throughout the experiment. Half of the trials in each block involved responses to the cued location and half involved responses to the uncued location. Cues and targets were equally likely to appear to the left or the right.

Results

The mean RTs for the errorless trials are presented in Figure 2. We analyzed the mean RTs with a 2 (cuing: cued or uncued) \times 2 (sequence: same side or opposite side) \times 2 (target location: left or right) analysis of variance (ANOVA). There was a reliable main effect of cuing, $F(1, 9) = 14.4, p < .01$, as cued locations had RTs that were 14.3 ms slower than those for uncued locations. This was the typical inhibition-of-return effect. No other reliable main effects were found. However, the Cuing \times Sequence interaction was reliable, $F(1, 9) = 13.1, p < .01$, with the inhibition of return greater for the same-side sequence (21.4 ms) than for the opposite-side sequence (7.3 ms). To compare the uncued conditions in both sequences, we conducted a 2 (sequence) \times 2 (target location) ANOVA for the uncued trials only. This analysis revealed no reliable differences, $F_s(1, 9) < 1$. In addition, we conducted separate 2 (cuing) \times 2 (target location) ANOVAs on both the same-side and opposite-side sequences. Reliable main effects of cuing were found for both the same-side, $F(1, 9) = 16.0, p < .005$, and opposite-side, $F(1, 9) = 7.0, p < .05$, sequences, indicating that inhibition of return existed for both sequences.

The percentages of correct responses are shown in Table 1. Approximately half of the errors were due to eye movements during the trial, and the other half of the errors were due to wrong keypress responses (this was true for all of the reported experiments). The number of correct responses was also analyzed with a 2 (cuing) \times 2 (sequence) \times 2 (target location) ANOVA. No reliable main effects, $F_s(1, 9) < 2, p_s > .20$, or interactions, $F_s(1, 9) < 4, p_s > .05$, were found.

To ensure that participants were looking at the fixation location and were not biased either toward or away from the location of the second peripheral cue, we analyzed the position of the participants' eyes 10 ms after presentation of the target. Overall, the mean eye position at that moment was 0.27° to the right of fixation, an amount not significantly different from 0° (i.e., straight ahead), $t(9) = 1.5, p > .15$. Furthermore, we analyzed the eye position data with a 2 (cuing) \times 2 (sequence) \times 2 (target location) ANOVA. No differences in eye position were found, $F_s(1, 9) < 2, p_s > .15$.

⁴ The 3° criterion was fairly liberal to minimize the need for recalibration of the eye movement monitor. Such recalibration is inevitable, because over time, the device moves relative to the participant or the participant moves a bit relative to the display. The 3° criterion, however, was strict enough that it virtually assured us of being able to detect any eye movements directed at either of the peripheral boxes, which were 7° from fixation. In Experiment 1, we also conducted some additional analyses of eye positions (see the *Results* section).

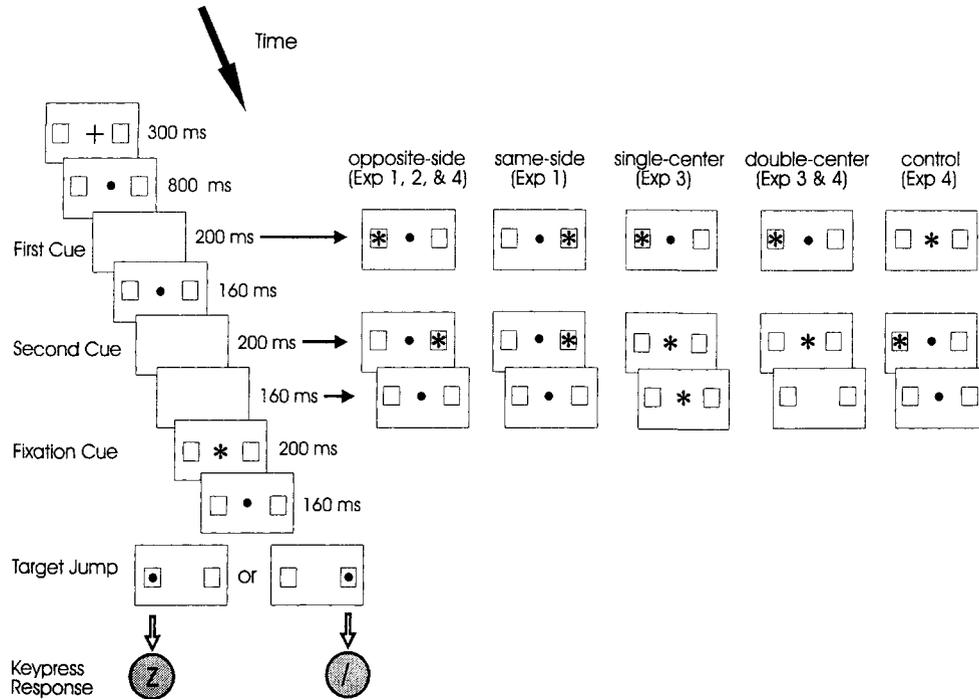


Figure 1. The events that occurred on each trial in Experiments (Exp) 1, 2, 3, and 4. The sequence of frames on the left shows the timing and the features of the trials that were common to all conditions. The specific first cue and second cue and the event immediately after the second cue depended on the condition (cuing sequence), and these are shown separately for the different cuing sequences. For each of the cuing sequences, an example of the first cue and the second cue from one trial type is shown, but there was also another trial type in which the cues (asterisks) were in the opposite locations (except for cues presented at the center).

Discussion

Experiment 1 yielded two important results. The first result was that RTs to uncued locations were equal in the same-side and opposite-side sequences. Recall that the uncued location in the opposite-side sequence was the location that had been cued at the beginning of the trial; however, in the same-side sequence, the uncued location was never cued. Apparently, the appearance of the second cue in the opposite-side sequence was sufficient to completely eliminate any inhibition that might have been present for the location of the first cue. As a result, detection of the target at the "uncued" location was equally good in both same-side and opposite-side conditions. Thus, these results suggest that inhibition of return may exist for only the one location that was most recently cued or attended.⁵ Apparently, when an exogenous cue summons attention to a new location, it displaces any inhibition that might have affected the previously attended location.

The second major result of Experiment 1 was that significantly more inhibition was found for the cued location in the same-side sequence (21.4 ms) than for the cued location in the opposite-side sequence (7.3 ms). Note that the two trial types were identical after the moment of presentation of the second cue at the cued location but were different before

that moment. In the opposite-side condition, participants had been cued to a target on the opposite side of fixation and presumably were attending there when the second cue was presented. However, in the same-side condition, they had been cued and were assumed to have been attending to the object at the location of the cue itself. Thus, the present results suggest that the amount of inhibition at a location may depend on the observer's attentional state prior to the cue to the location. The second cue might have been less effective in capturing the participants' attention in the opposite-side sequence compared with the same-side sequence. If the cue was less effective initially, then participants would have had less difficulty returning their attention there later (*i.e.*, less inhibition of return).

⁵ When we say the most recently cued location, we mean the location cued immediately before presentation of the final fixation cue. This is because the fixation cue was necessary in order to remove attention before we could measure the ease (or the difficulty) with which attention can be returned, which, of course, was our primary concern. We should also note that we could not be certain that our cues were effective in summoning attention; that is addressed in Experiment 2.

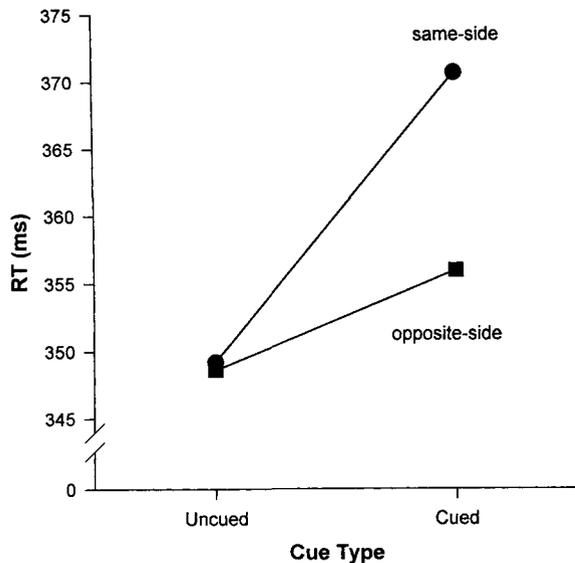


Figure 2. The mean reaction times (RTs) for targets at the cued and uncued locations in the opposite-side and same-side sequences of Experiment 1. The cued location in the opposite-side sequence is the location of the second cue (i.e., the most recently cued location).

Experiment 2

The hallmark of covert orienting of attention is facilitation for the cued location at short cue-stimulus intervals and inhibition at the cued location at long cue-stimulus intervals (e.g., Maylor, 1985; Posner & Cohen, 1984). In Experiment 1, we demonstrated the latter effect (i.e., inhibition of return) for the cued location at a relatively long cue-stimulus interval. However, we did not study short cue-stimulus intervals. This left open the possibility that the phenomenon studied in Experiment 1 might not have been the typical inhibition-of-return effect that we assumed it was. Indeed, we had no direct evidence that our exogenous stimuli were

Table 1
Percentages of Correct Responses for Experiments 1, 2, 3, and 4 as a Function of Cuing Condition and Sequence

Experiment and cuing sequence	Cuing condition	
	Cued	Uncued
Experiment 1		
Same-side sequence	90	93
Opposite-side sequence	95	93
Experiment 2		
Short cue-stimulus interval	92	93
Long cue-stimulus interval	95	94
Experiment 3		
Single-center sequence	92	93
Double-center sequence	91	93
Experiment 4		
Opposite-side sequence	94	93
Double-center sequence	94	94
Control sequence	95	96

even capable of summoning the participants' attention as we assumed they had. To rule out that possibility, we conducted the present experiment. In this experiment, we used the opposite-side sequence from Experiment 1 with two different intervals between presentation of the second cue and presentation of the imperative stimulus. If attention were being covertly oriented to the cued locations, then the present experiment would yield facilitation at the short cue-stimulus interval and inhibition at the long cue-stimulus interval.

Method

Participants. Eight students from Washington University participated in a single 1-hr session. All of the participants had normal uncorrected vision, and none had any prior knowledge of the purposes of the experiment. Each student was paid \$6 for participating.

Apparatus, procedure, and design. Experiment 2 used the opposite-side cuing sequence from Experiment 1 (see Figure 1) but with two different intervals between the second cue and the target jump. The *long cue-stimulus interval* condition was exactly the same as the opposite-side sequence used in Experiment 1. In Experiment 1, a total of 520 ms elapsed between the offset of the second cue and the target jump to which participants were required to respond. During that 520-ms period, the fixation cue was presented for 200 ms, as it had been in Experiment 1. In the *short cue-stimulus interval* condition, the target jump occurred 80 ms after the offset of the second cue. In this condition, the fixation cue was not presented. The use of a fixation cue with the long cue-stimulus interval and its absence in the short interval were similar to the design used by Maylor (1985), Posner et al. (1985), and Rafal et al. (1989). There were four conditions overall, two cue-stimulus intervals (80 ms and 520 ms) with two types of trials (fixation dot jumped to either the cued or the uncued target location). As in Experiment 1, we defined the cued location as the location of the second cue, and the uncued location as the location where the first cue appeared. The experimental session consisted of 10 blocks of 32 trials each, with half of the trials in each block involved with responses to the cued location and half involved with responses to the uncued location. Conditions were randomly presented throughout the experiment. Cues and targets were equally likely to appear to the left or the right.

Results

The mean RTs for the errorless trials are presented in Figure 3. We analyzed the mean RTs using a 2 (cuing) \times 2 (cue-stimulus interval: short or long) \times 2 (target location) ANOVA. Reliable main effects were found for cuing, $F(1, 7) = 37.1$, $p < .001$, and for cue-stimulus interval, $F(1, 7) = 48.4$, $p < .001$. These results indicate that RTs were slower overall for cued locations (408 ms) than for uncued locations (399 ms) and that RTs were slower at the short cue-stimulus interval (439 ms) than at the long cue-stimulus interval (369 ms). Importantly, the Cuing \times Cue-Stimulus Interval interaction was reliable, $F(1, 7) = 70.9$, $p < .0005$, with facilitation at the short interval (cued = 426 ms and uncued = 452 ms) and inhibition at the long interval (cued = 373 ms and uncued = 365 ms). No other reliable

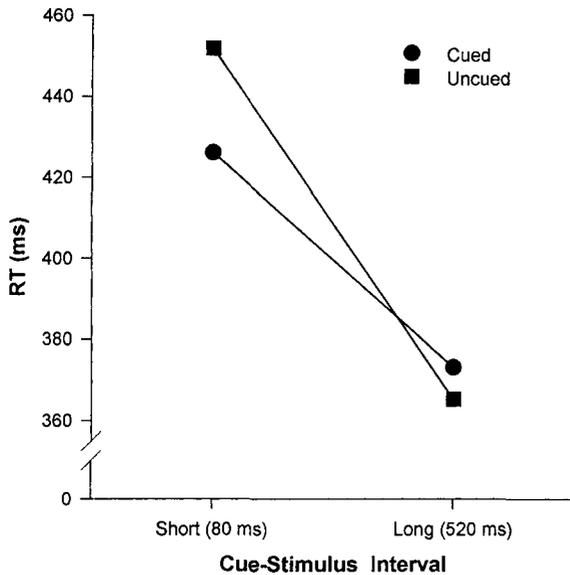


Figure 3. The mean reaction times (RTs) for the cued and uncued locations in the opposite-side sequences of Experiment 2 for short and long cue-stimulus intervals.

main effects or interactions were found, $F_s(1, 7) < 2$, $p_s > .20$.

We ran separate 2 (cuing) \times 2 (target location) ANOVAs on each of the two cue-stimulus intervals to determine if the short interval produced facilitation while the long interval produced inhibition. Indeed, the analysis of the short-interval condition indicated that the cued location was reliably faster than the uncued location, $F(1, 7) = 70.5$, $p < .0005$. Also, the analysis of the long cue-stimulus interval condition indicated that the cued location was reliably slower than the uncued location, $F(1, 7) = 21.6$, $p < .005$. No other main effects or interactions were reliable, $F_s(1, 7) < 1.5$, $p_s > .30$.

The percentages of correct responses are shown in Table 1 and were analyzed with a 2 (cuing) \times 2 (cue-stimulus interval) \times 2 (target location) ANOVA. No reliable main effects or interactions were found, $F_s(1, 7) < 3.5$, $p_s > .10$, although there was a trend toward fewer correct responses at the short cue-stimulus interval, $F(1, 7) = 4.3$, $p < .10$.

Discussion

In this experiment, the peripheral cues resulted in facilitation at the cued location at short cue-stimulus intervals and inhibition at long cue-stimulus intervals. This is the same pattern that has been reported by other researchers who have studied exogenous covert orienting and inhibition of return (e.g., Maylor, 1985; Posner & Cohen, 1984; Rafal et al., 1989). Because the stimuli here were the same as those used in Experiment 1, these results support our assumption that the present paradigm can effectively manip-

ulate covert orienting and that the inhibition that we observed was indeed the typical inhibition-of-return effect. We now turn to questions about details of the phenomenon.

Experiment 3

Experiment 1 provided evidence that inhibition of return occurs for only the one most recently attended location. Apparently, the appearance of a second cue in a new location (in the opposite-side sequence) completely removed the inhibition associated with the first cued location. We had suggested that the second cue somehow displaced the inhibition that might have affected the location of the first cue. However, inhibition of return is known to decay with the passage of time (Vaughan, 1984). Thus, it is possible that such decay might have contributed to the results of Experiment 1. We designed Experiment 3 to provide a more direct test of the extent to which the lack of inhibition at the first cued location in the opposite-side sequence of Experiment 1 can be attributed to either displacement of the inhibition by the second cue or simple decay of the inhibition over the lengthy cue-to-target interval. Contingent on inhibition to the first cued location being displaced and not decaying, in this experiment we explored the extent to which the fixation location (i.e., not a peripheral target) could serve as an effective cue location. That is, if displacement of inhibition at previously attended locations did occur, would a cue at the fixation location also displace the inhibition, or must other (peripheral) target locations be cued for displacement of inhibition to occur?

Method

Participants. Ten students from Washington University participated in a single 1-hr session. All of the participants had normal uncorrected vision, and none had any prior knowledge of the purposes of the experiment. Each student was paid \$6 for participating.

Apparatus, procedure, and design. Experiment 3 was the same as Experiment 1 except that different cuing sequences were used. These sequences appear in Figure 1. The *single-center* sequence consisted of a first cue to a target location and then the fixation cue at the fixation location. The *double-center* sequence consisted of a first cue to one of the two targets, a second cue presented at the fixation location, and then the fixation cue, also at the fixation location. The two sequences were identical except for the 160-ms interval beginning 200 ms after the onset of the second cue. No changes occurred in the display during this time in the single-center sequence; however, the center of the display was blank during this time in the double-center sequence. This had the appearance of an additional flash at the center in the double-center sequence. Note that the amount of time between the onset of the first fixation cue and the presentation of the target stimulus was 720 ms in both sequences. There were four conditions overall, two sequences (single-center and double-center) with two types of trials (fixation dot jumped to either the cued or the uncued target location). Ten blocks of 32 trials each were used, and each condition was randomly presented throughout the experiment. Half of the trials in each block involved responses to the cued location and

half involved responses to the uncued location. Cues and targets were equally likely to appear to the left or the right.

Results

Mean RTs for the errorless trials are presented in Figure 4 and were analyzed using a 2 (cuing) \times 2 (cuing sequence) \times 2 (target location) ANOVA. No reliable main effects were found for cuing, cuing sequence, or target location. However, the interaction between cuing and cuing sequence was reliable, $F(1, 9) = 8.7, p < .02$, with the inhibition-of-return effect much greater for the single-center sequence (13.9 ms) than for the double-center sequence (0.4 ms). We performed separate 2 (cuing) \times 2 (target location) ANOVAs, on each of the two sequences to determine if inhibition of return was produced. Inhibition of return was found for the single-center sequence, with the cued location reliably slower than the uncued location, $F(1, 9) = 6.3, p < .05$. The double-center sequence failed to produce inhibition of return, $F(1, 9) < 1$. To determine if the uncued conditions in both sequences were alike, we conducted a 2 (cuing sequence) \times 2 (target location) ANOVA on only the uncued trials, and no differences were found, $F_s(1, 9) < 1.5, p_s > .10$.

The percentages of correct responses are shown in Table 1. These were analyzed with a 2 (cuing) \times 2 (cuing sequence) \times 2 (target location) ANOVA. No reliable main effects, $F_s(1, 9) < 2, p_s > .20$, or interactions, $F_s(1, 9) < 3, p_s > .10$, were found.

Discussion

The results of Experiment 1 suggested that each new cued location might displace older previously cued locations

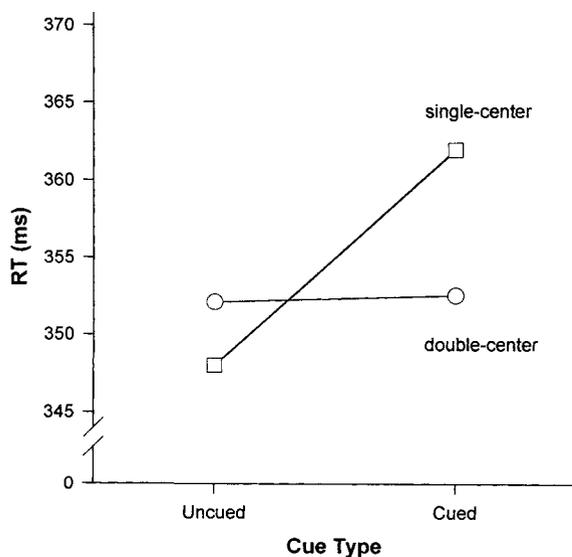


Figure 4. The mean reaction times (RTs) for the cued and uncued locations in the single-center and double-center sequences of Experiment 3.

from memory. Thus, inhibition appeared to affect only the one most recently cued location. If those conclusions were correct, then inhibition of return would be expected for the single-center sequence but not for the double-center sequence. This is because the additional cue present in the double-center sequence would be expected to eliminate any inhibition associated with the first cued location. That is precisely the pattern observed in the present experiment, with a 14-ms difference between cued and uncued locations in the single-center sequence, whereas the double-center sequence produced less than a 1-ms difference. The explanation for the lack of inhibition to the cued location in the double-center sequence must be displacement, not decay, of the cued location. This is because the delay between the initial cue away from the cued location and the appearance of the target was the same for both sequences.⁶

We also should note an important feature of the second cue in the double-center condition. That cue completely eliminated all inhibition. A similar result was obtained in the opposite-side condition of Experiment 1 for targets at the location of the first cue. However, in the present experiment, the event that succeeded in eliminating inhibition was an exogenous cue presented at the fixation location, whereas in Experiment 1, the event was an exogenous cue at the opposite target location. Maylor and Hockey (1985) have shown that exogenous cues at the central fixation location can effectively produce inhibition of return, also suggesting that the fixation location does not have a special status. Apparently, any exogenous cue is sufficient to remove the inhibition to an earlier cued location (assuming that such a second cue is followed by a cue at fixation prior to the appearance of the target).

Experiment 4

Experiment 4 had a twofold purpose. First, it was designed to replicate the major findings of Experiments 1 and 3. Those findings were that inhibition of return occurs for only the one most recently cued location (inhibition at an earlier cued location is displaced by a more recent cue) and that the recent cuing history may influence the effectiveness of a subsequent cue and, in turn, may affect the amount of inhibition that will occur at a cued location. To reexamine these effects, we included the double-center sequence from Experiment 3 and the opposite-side sequence from Experiment 1.

The second purpose of Experiment 4 was to determine more precisely the magnitude of the reduction in inhibition that results from a prior cue away from the eventual target location. Recall that Experiment 1 involved a comparison between a cuing sequence in which opposite locations were cued (the opposite-side sequence) and a sequence in which the same location was cued twice (the same-side sequence).

⁶ We were assuming that the presentation of the initial cue away from the cued target was the first time at which inhibition might be present and hence the time from which the inhibition might begin to decay. We thank an anonymous reviewer for helpful comments regarding this issue.

There it was found that the inhibition to the target was greatly reduced in the opposite-side sequence compared with the same-side sequence. However, the repeated cuing of the target in the same-side sequence was unusual, perhaps making the target much more salient than a single cue would. As a result, the amount of inhibition observed in the same-side sequence might have been somewhat inflated. If so, then the difference observed between the two cuing sequences might have overestimated the true magnitude of the reduction in inhibition afforded by a prior cue. To explore this possibility, a new sequence was added that was similar to the same-side sequence but without the repeated cuing. Such a sequence also has the virtue of being similar to the kinds of attentional cuing sequences that have been used in previous studies of inhibition of return (e.g., Abrams & Dobkin, 1994b; Tipper et al., 1994).

Method

Participants. Eighteen students from Washington University participated in a single 1-hr session. All of the participants had normal uncorrected vision, and none had any prior knowledge of the purposes of the experiment. Each student was paid \$6 for participating.

Apparatus, procedure, and design. Experiment 4 used the double-center cuing sequence from Experiment 3 and the opposite-side cuing sequence from Experiment 1. In addition, one new sequence, the control sequence, was added. All of the sequences are shown in Figure 1. In the control sequence, the first cue was presented at the fixation location, and the second cue was presented at a target location. The initial center fixation cue was used to keep the number of cuing events in each sequence the same. The timing of the control sequence was exactly the same as that of the double-center and opposite-side sequences. There were six conditions overall, three sequences (double-center, opposite side, and control) with two types of trials (fixation dot jumped to either the cued or the uncued location). The conditions were randomly presented throughout the experiment. The experimental session consisted of 10 blocks of 36 trials each, with half of the trials in each block involved with responses to the cued location and half involved with responses to the uncued location. Cues and targets were equally likely to appear on the left or the right.

Results

The mean RTs for the errorless trials are presented in Figure 5. We analyzed RTs using a 2 (cuing) \times 3 (sequence) \times 2 (target location) ANOVA. Overall, participants were reliably slower (7.8 ms), $F(1, 17) = 7.3, p < .02$, in the cued conditions compared with the uncued conditions. There was also a reliable main effect of sequence, $F(2, 34) = 27.8, p < .001$, which was due to longer RTs in the control sequence than in either the double-center sequence or the opposite-side sequence. There was no main effect of target location, $F(1, 17) < 1.5, p > .25$. Most important, the Cuing \times Sequence interaction was reliable, $F(2, 34) = 7.4, p < .01$, indicating that the different sequences produced different amounts of inhibition of return (14.8 ms for the control sequence, 7.4 ms for the opposite-side sequence, and

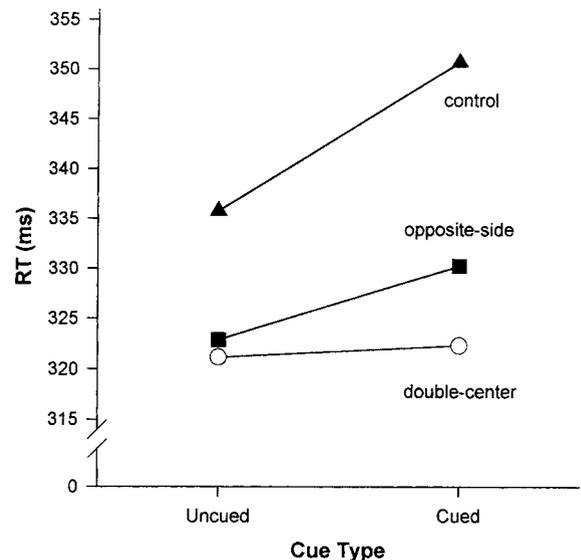


Figure 5. The mean reaction times (RTs) for the cued and uncued locations in the double-center, opposite-side, and control sequences of Experiment 4.

1.2 ms for the double-center sequence). No other interactions were found to be reliable.

We ran separate 2 (cuing) \times 2 (target location) ANOVAs on each of the three sequences to determine what sequences demonstrated inhibition of return. Both the control sequence $F(1, 17) = 15.1, p < .01$, and the opposite-side sequence, $F(1, 17) = 4.7, p < .05$, showed reliably slower responses to the cued location than to the uncued location. In contrast, no inhibition of return was found for the double-center sequence, $F(1, 17) < 1$. There were no reliable main effects of target location, $F_s(1, 17) < 3, p_s > .10$, nor were there Cuing \times Target Location interactions, $F(1, 17) < 1$, for any of the three sequences.

The percentages of correct responses (shown in Table 1) were also analyzed with a 2 (cuing) \times 3 (sequence) \times 2 (target location) ANOVA. No reliable main effects, $F_s(1, 17) < 1.5, p_s > .20$, or interactions, $F_s(2, 34) < 2, p_s > .10$, were found.

Discussion

The two major findings from Experiments 1 and 3 were that the opposite-side sequence produced a small amount of inhibition of return and that the double-center sequence did not produce any inhibition of return. Both of these effects were replicated in the present experiment: The double-center sequence resulted in only 1.2 ms of inhibition, and the opposite-side sequence produced approximately half of the inhibition that the control condition did (7.4 ms and 14.8 ms, respectively). Furthermore, the RT to the uncued location of the opposite-side sequence equaled the RT in the double-center sequence, suggesting that no inhibition remained to the initially cued location in the opposite-side

sequence. These findings add support to the previous finding that inhibition of return exists at one previously cued location and that each newly cued location displaces a previously cued location from memory.

The results from Experiment 4 also suggest that the same-side sequence used in Experiment 1 did indeed overestimate the inhibition to the cued location. A greater amount of inhibition was produced by cuing one location twice (21.4 ms in the same-side sequence of Experiment 1) than if a single location was cued only once (14.8 ms in the control sequence of the present experiment).

An unexpected finding from Experiment 4 was that the control sequence yielded longer RTs for both the cued and uncued locations compared with both of the other sequences. Note that the uncued location was never cued in either the control sequence or the double-center sequence. If no inhibition existed for the uncued location, then RTs would be expected to be equal for uncued locations in those two conditions. One possible explanation for the longer RTs found in the control sequence involves the return of attention to an inhibited location. Recall that in the control sequence the fixation location was first cued, then there was a cue to a target location, and finally the fixation location was cued again. Presumably, a participant must overcome some inhibition in order to return attention to the fixation location when the fixation cue is presented. It may be that returning attention to an inhibited location results in a bias against the subsequent removal of attention from that location. Such a bias could produce the elevated RTs found in the control sequence. Further research is needed to determine more precisely the roles played by cues at target and nontarget locations and cues that occur at inhibited (i.e., recently attended) locations.

General Discussion

The present experiments have revealed a number of important characteristics of inhibition of return when exogenous cues are presented at several locations in succession. Experiment 1 showed that the inhibition exists for only the one most recently cued location (prior to the final central cue). The magnitude of the inhibition, however, does depend on events that occurred before attention was directed to that one inhibited location. In particular, the amount of inhibition at a cued location was reduced by prior cuing at a different location. Experiment 2 showed that our exogenous cuing paradigm produced an initial facilitation at the cued location that was later followed by inhibition of return. This suggests that our cues were effectively summoning the participants' attention. Experiment 3 provided further support for the conclusion that inhibition exists for only the one most recently cued location and showed that a subsequent cue displaces previously cued locations, thus eliminating a decay-based interpretation of the earlier results. Experiment 4 extended the results by permitting a comparison with a condition similar to those used by previous researchers of inhibition of return. That experiment suggested that a special status may exist for a location that is selected despite

the presence of inhibition against returning to it: Once such a location is reselected, people may be biased against moving attention away from it.

Taken together, the present results suggest that people are able to retain information about recently attended and then unattended locations. The inhibition to return attention to such locations is not all-or-none but instead appears to be modulated by the strength of the initial selectivity with which the location was attended. Nevertheless, inhibition appears to exist for only one location. These results lead to an unexpected answer to a question raised at the outset. In particular, although inhibition of return does indeed bias visual searches toward fresh sources of input, there appears to be very little memory for the prior history of an ongoing search. Despite the potential benefits of such a memory, it apparently does not exist or exists only in a limited form. Perhaps this is not so surprising given the enormous number of factors, both endogenous and exogenous, that may guide or attract the focus of attention.

Relation to Previous Research

Certain aspects of our results are closely related to earlier work on inhibition of return. For example, Posner and Cohen (1984) and Maylor (1985) also examined the extent to which more than one location might be inhibited at the same time. They approached this question by simultaneously presenting attentional cues at multiple locations, in contrast to the successive presentation used in the present study. Indeed, their results were quite different from ours: In both studies, inhibition existed for both previously cued locations. With successive presentation, we found that inhibition existed for only a single previously cued location. Presumably, the procedural difference accounts for the different results; however, certain aspects of our conclusions must be modified to accommodate them. In particular, we have suggested that a sort of memory exists for prior cued or attended locations with a capacity limited to one inhibited location. Clearly, the results of Maylor and of Posner and Cohen suggest that two locations may be inhibited at the same time if they are cued simultaneously, not successively. Thus, perhaps the memory for to-be-inhibited locations includes the one or more locations that were cued in a single moment in time or a narrow time interval. Such a mechanism would be consistent with the present results from successive cuing as well as the previous results involving multiple simultaneous cues.

There has been one previous study that did use multiple successively cued locations. As we mentioned earlier, Maylor and Hockey (1987) had participants respond to peripheral targets that were either at the location of an earlier exogenous cue or at another location. They analyzed their data in terms of not only the relation between the target and the cue on a given trial but also the location of the target on the previous trial. Participants were slowest to detect targets that were at cued locations that had been the target on the previous trial, which is consistent with the large inhibition-of-return effect we found in the same-side condition of

Experiment 1. However, inspection of their data revealed that the effect of prior target location was greater than that of present cue location. Thus, it appears that much of their effect may be due to processes associated with an overt response to a prior target and not to processes involved in covert orienting to exogenous cues. The latter processes were the focus of the present inquiry. More work is needed to learn more about these distinct components that may contribute to inhibition of return.

Implications for Goal-Directed Selection

The present studies were conducted using stimuli that appeared suddenly in the display, and thus our conclusions apply most directly to the mechanisms underlying stimulus-driven attentional capture (for an overview, see Yantis, 1993). However, many of one's searches of the visual world might be expected to involve a more centrally controlled, goal-directed kind of selection. The latter process might be less affected by sudden onsets and more under the influence of task constraints and the objectives of the observer. It is not clear to what extent our results and conclusions would also apply to such goal-directed searches, although there is some evidence that suggests that goal-directed selection may operate somewhat differently. For example, if the movement of attention is signaled entirely by a central cue (i.e., endogenously), then no inhibition of return will occur after attention is removed, even though such a cue can effectively produce the initial attentional movements in the first place (Posner & Cohen, 1984; Rafal et al., 1989). These issues undoubtedly require further work to resolve.

Relation to Eye Movement Mechanisms

Similarly, it is difficult to determine precisely how the present results might be related to the component of inhibition of return that is related to eye movements. Abrams and Dobkin (1994b) found that people were slower to move their eyes to the location of a previously cued object, even though participants did not need to detect a signal at the inhibited location. They concluded that a portion of inhibition of return involves inhibited target detection, but another component involves inhibited eye movements. The present study examined only the target detection component because eye movements were not used as responses. Because some differences were found between properties of the eye movement and the detection components (see Abrams & Dobkin, 1994b), it is unclear to what extent the present results would also apply to the eye movement component. A number of other sources also suggest close links between eye movements and inhibition of return (e.g., Abrams & Dobkin, 1994a; Rafal et al., 1989).

Conclusion

We have shown that inhibition of return uses only a very limited memory for previously attended locations during an ongoing exogenously cued search. The inhibition appears to

affect only the one most recently attended location. Subsequent deployments of attention (even repeated reorienting to a single location) will effectively displace the memory for previously attended objects. Despite these new insights, a number of important questions remain unanswered. Our hope is that the present results provide a useful framework within which these additional questions can be addressed.

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