

Spatially Diffuse Inhibition Affects Multiple Locations: A Reply to Tipper, Weaver, and Watson (1996)

Richard A. Abrams and Jay Pratt
Washington University

S. Tipper, B. Weaver, and F. Watson (1996) suggest that J. Pratt and R. A. Abrams's (1995) failure to find inhibition of return for more than the most recently cued location was because their 2-target display did not adequately capture some of the complexity of real-world visual environments. However, Tipper et al. tested a special case because they always cued 3 out of 4 potential targets (allowing cued and uncued locations to be segregated into 2 spatial regions). The authors show that only the 1 most recently cued location will be inhibited when 2 nonadjacent targets out of 4 possible targets are cued, but both cued locations will be inhibited when they are adjacent. Also, only the 1 most recently cued location was inhibited when 3 nonadjacent targets out of 6 potential target locations were cued. Thus, in a complex environment in which several cued locations are interspersed among noncued locations, inhibition of return will occur for only the 1 most recently attended location, consistent with conclusions of Pratt and Abrams.

Pratt and Abrams (1995) presented cues to attract participants' attention to two peripheral locations in succession, and then back to a central fixation mark. They found that participants were inhibited in detecting targets at only the one most recently cued location. Pratt and Abrams concluded that the mechanism responsible for inhibition of return has a very limited memory—limited to the one most recently attended location. Tipper, Weaver, and Watson (1996), however, suggested that Pratt and Abrams' paradigm was inappropriate because it involved the use of only two target locations. As a result, if participants were to be inhibited in returning their attention to both targets (after both had been cued) they would essentially be inhibiting all potential target locations. Such behavior, as Tipper et al. note, would be very inefficient for effective visual searches. In support of their claim, Tipper et al. showed that participants were indeed slower to detect targets appearing at any of three previously cued locations when there were four possible target locations.

We agree with Tipper et al.'s (1996) suggestion that a two-target situation may be somewhat limited, and we welcome their extension of our investigation to more complex stimulus displays. However, it is possible that the particular stimulus arrangement that Tipper et al. used is itself somewhat limited. In particular, participants in their study were cued successively to three out of four potential locations, and then subsequently received a target at one of the four

locations. However, cueing three out of four locations may have allowed participants to conveniently partition the visual world into two general regions: (a) a region that had been cued, and (b) a region that had not been cued. If it is possible for inhibition of return to operate over a broad spatial area, then the Tipper et al. results may not actually demonstrate inhibition at multiple individual locations, but instead may reflect a diffuse, spatially distributed type of inhibition that covers an entire area. In fact, there is evidence that inhibition of return and other visual attentional phenomena may select or inhibit entire hemifields (Berlucchi, Tassinari, Marzi, & Di Stefano, 1989; Hughes & Zimba, 1985; Rizzolatti, Riggio, Dascolo, & Umiltà, 1987; Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987).

To investigate this possibility, we replicated Tipper et al.'s (1996) basic result and also examined two new situations: (a) a situation in which two out of four targets are cued, and (b) a situation in which three out of six targets are cued. According to Tipper et al., participants should be inhibited to detect targets at each of the previously cued locations in each of these new situations.

Experiment 1

The purpose of this experiment was to replicate the Tipper et al. (1996) results.

Method

The method was very similar to that used by Tipper et al. (1996) with some minor changes due to equipment differences.

Participants. Twelve Washington University undergraduates each served in a single 30-min session. They were paid \$5 for their time.

Procedure. At the beginning of each trial participants saw five white boxes ($1^\circ \times 1^\circ$) displayed on a black screen. One box was in the center of the display and served as a fixation marker. The

Richard A. Abrams and Jay Pratt, Department of Psychology, Washington University. Jay Pratt is now at the Department of Psychology, University of Toronto, Toronto, Ontario, Canada.

The research was supported by Grant R29-MH45145 from the National Institutes of Health.

Correspondence concerning this article should be addressed to Richard A. Abrams, Campus Box 1125, Department of Psychology, Washington University, St. Louis, Missouri 63130. Electronic mail may be sent via Internet to rabrams@artsci.wustl.edu.

other four boxes were located at the corners of an imaginary $10^\circ \times 10^\circ$ square centered on the fixation marker. After a 1,120-ms delay, the first cue was presented. This consisted of filling in one of the four peripheral squares, waiting 80 ms, and then emptying the square. After a 180-ms delay, the second cue was presented in the same manner as the first. The third cue followed after another 180-ms delay. Then, 180 ms after the offset of the third cue, the center box was illuminated in the same manner as the peripheral boxes had been illuminated. The central box was emptied 80 ms later, and then, after a 520-ms delay, the target was presented on 80% of the trials. The target consisted of filling in one of the four peripheral boxes in the same manner as had been used for the cues. The participant's task was to press the space bar on the keyboard in front of them as soon as the target had been presented. On 20% of the trials, no target was presented, and participants were instructed to refrain from responding on these catch trials.

When the target was presented, it was equally likely to appear in any of the four peripheral boxes. Thus, 25% of the noncatch trials involved targets presented at the location of the first cue. We call these *cued-first* trials. Similarly, 25% of the targets were at the locations of the second and third cues (*cued-second* and *cued-third*, respectively). Finally, 25% of the noncatch trials involved targets presented at the *uncued* location. In addition to a practice block of 20 trials, participants performed 240 test trials—48 in each of the four noncatch conditions, and 48 catch trials. The 48 trials in each condition included two instances of each of the 24 possible orders of cues when selecting three out of four locations to cue.

Results and Discussion

Mean keypress reaction times in each of the four conditions are shown in Figure 1. As Tipper et al. (1996) found, participants were fastest to respond to the target that had not been cued (i.e., the uncued condition), and latencies increased for the cued-first, cued-second, and cued-third conditions, $F(3, 33) = 7.2, p < .005$. Paired t tests revealed statistically reliable inhibition in each of the three cued conditions relative to the uncued condition, $t_s(11) > 3.4, p_s < .01$.

The present experiment successfully replicated Tipper et al.'s (1996) finding of inhibition of return at each of three successively cued locations.

Experiment 2

As noted in the introduction, when three out of four targets are cued, it is possible that participants are able to partition visual space into two general regions: a cued region and an uncued region. If so, then the inhibition of return obtained in Experiment 1 and by Tipper et al. (1996) may not really reflect inhibition to each of the three cued locations, but instead, may reflect inhibition to a single broad region of visual space. To examine this possibility, we conducted exactly the same experiment as Experiment 1; however, in Experiment 2 we cued only two of the four target locations. We examined possible inhibition to each of the two cued locations when the two locations were adjacent, and thus might facilitate grouping that would lead to spatially diffuse inhibition, and when the two locations were

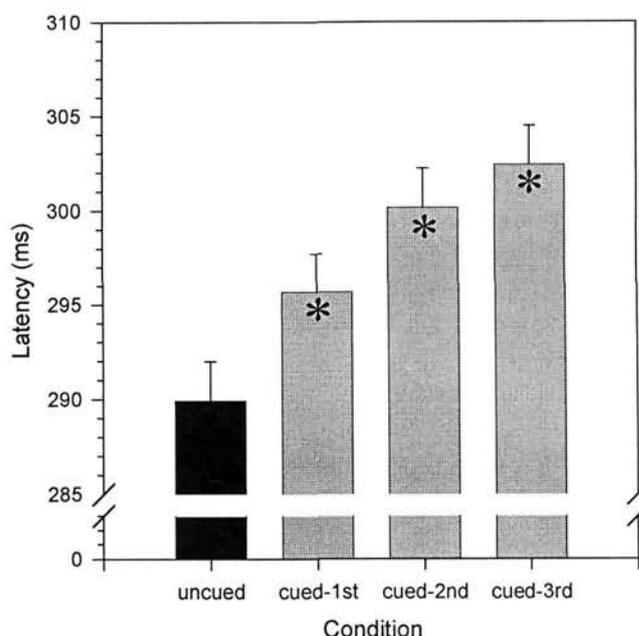


Figure 1. Mean keypress latencies from Experiment 1. In the experiment, three out of four locations were cued in succession on each trial prior to the appearance of the target. Asterisks indicate the conditions that differed from the uncued condition. The black bar represents the mean reaction time for the uncued condition, and the gray bars represent the mean reaction time for the various cued conditions.

not adjacent, rendering such grouping and inhibition less likely.

Method

Participants. Twelve Washington University undergraduates who had not served previously each served in a single 30-min session. They were paid \$5 for their time.

Procedure. This experiment was identical to Experiment 1 with only one exception: The third cue and the delay that followed it were removed. Hence, the present experiment included uncued, cued-first, and cued-second conditions. Participants completed 48 catch trials, 48 trials in each of the cued conditions, and 96 trials in the uncued condition. (Because the target was equally likely to be any of the four locations, it was twice as likely to appear at an uncued location than at any one of the two cued locations.) Each possible combination of two cues selected out of four occurred equally often in each of the conditions.

Results

The mean keypress latencies are shown in Figure 2. Results for cued-first and cued-second conditions are shown separately for trials on which the two cues were presented at adjacent locations (i.e., both were either above, below, to the left, or to the right of fixation), as opposed to opposite (i.e., nonadjacent) locations. Evaluating these five conditions together revealed a reliable overall effect of condition, $F(4, 44) = 11.3, p < .0001$. Separate t tests showed that

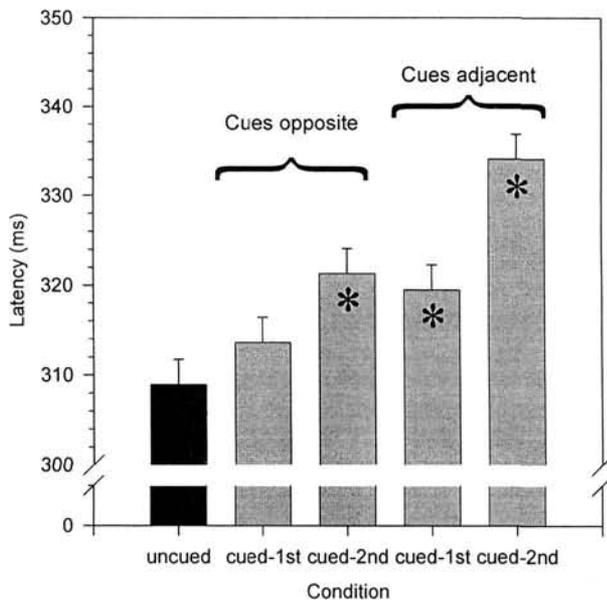


Figure 2. Mean keypress latencies from Experiment 2. In the experiment, two out of four locations were cued in succession on each trial prior to the appearance of the target. Asterisks indicate the conditions that differed from the uncued condition. The black bar represents the mean reaction time for the uncued condition, and the gray bars represent the mean reaction time for the various cued conditions.

each of the cued conditions was slower than uncued with the exception of the cued-first opposite [for cued-first opposite, cued-second opposite, cued-first adjacent, cued-second adjacent, the results were the following: $t(11) = .99$, ns ; $t(11) = 4.9$, $p < .001$; $t(11) = 2.4$, $p < .05$; $t(11) = 6.1$, $p < .0005$, respectively].

Discussion

When the two cues were in adjacent locations, participants were inhibited in returning attention to both previously cued locations, which is consistent with the results of Experiment 1 and Tipper et al. (1996), and in contrast to the results of Pratt and Abrams (1995). However, when the two cues were opposite one another, participants were only inhibited in returning to the one most recently cued location, which is consistent with the results of Pratt and Abrams (who used a display that contained two targets on opposite sides of fixation). Apparently, when participants are able to easily partition the visual world into cued and uncued regions, they can be inhibited in returning attention to a region that includes several previously cued locations. However, when such a segmentation is not possible, inhibition of return occurs only to the one most recently cued location.

Experiment 3

In Experiment 3, we have proposed that inhibition of return may operate on broad regions of space as well as

individual discrete locations. It is important to note that it appears to be that only the one most recently cued discrete location will be affected by inhibition of return when the cued locations are noncontiguous and interspersed among noncued target locations. However, a broad region of space that includes several prior cues may also be affected if all potential target locations in the region have been cued. The present experiment represents one further test of these ideas. Here we presented participants with three cues in succession; however, there were six possible locations at which the cues could be presented. We constrained the display so that cues were always presented in nonadjacent locations. As a result, noncued potential target locations were interspersed among the cued locations. Under these conditions we would not expect participants to experience inhibition of return for an entire region. Instead, we would expect them to be slower to detect targets at the third (i.e., the most recent) cued location but not at the locations of the first two cues, relative to targets at uncued locations. Such a result would be consistent with the conclusions of Pratt and Abrams (1995).

Method

Participants. Sixteen Washington University undergraduates who had not served previously each served in a single 30-min session. They were paid \$5 for their time.

Procedure. This experiment was identical to Experiment 1 with only one exception: There were six possible target locations here (as opposed to four in Experiment 1). The target locations were arranged around a circle, with targets directly above and below fixation, and others spaced 60° apart. Three cues were always presented in succession, as in Experiment 1. Thus, this experiment included uncued, cued-first, cued-second, and cued-third trials. Because the cues were always presented in nonadjacent locations, there were a total of 12 possible orders of cues. The target could appear in any of the six locations, regardless of the cueing order, for a total of 72 (6×12) distinct trials. Participants first completed a practice block of 20 trials. They then completed two blocks that each contained 84 trials (one instance of each of the 72 possible trials, plus 12 catch trials).

Results and Discussion

Mean keypress reaction times to detect the target onset are shown in Figure 3 for each condition. Overall, reaction times differed between conditions, $F(3, 45) = 2.86$, $p < .05$. Individual t tests revealed that only the cued-third condition was significantly different from the uncued condition, $t(15) = 9.3$, $p < .05$; for the other comparisons, $ts(15) > 1.2$, $p > .2$. Thus, inhibition of return influenced only the one most recently cued of the three cued locations.

General Discussion

In the course of exploring the visual world, people move their attention from location to location very rapidly. Efficient visual searches would be facilitated by a mechanism that biases people against attending to recently attended locations, assuming that people have terminated processing

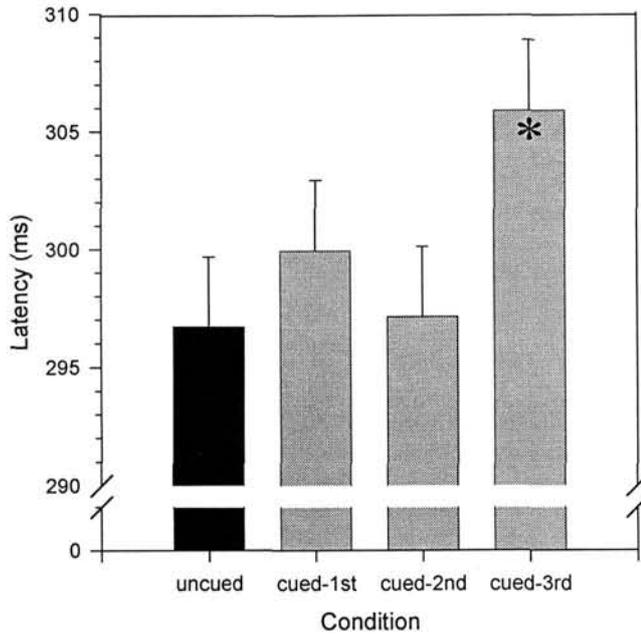


Figure 3. Mean keypress latencies from Experiment 3. In the experiment, three nonadjacent out of six locations were cued in succession on each trial prior to the appearance of the target. The asterisk indicates the condition that differed from the uncued condition. The black bar represents the mean reaction time for the uncued condition, and the gray bars represent the mean reaction time for the various cued conditions.

at such locations. Inhibition of return is thought to represent such a mechanism. In the present study we examined questions about the scope and extent of the area that will be inhibited. On a priori grounds it could be argued that some memory would be useful for perhaps the last several attended locations. On the other hand, maintaining such a memory might impose a cost. Indeed, Pratt and Abrams (1995) had concluded that despite the potential benefits of maintaining a memory of several previously attended locations, only the one most recently cued of two cued locations was affected by inhibition of return.

Pratt and Abrams (1995), however, only examined situations with two potential target locations. As Tipper et al. (1996) pointed out, such a situation has some limitations. In particular, when both locations are cued, participants might be confronted with the possibility of inhibiting responses to all potential target locations; a very inefficient behavior. In the present investigation we examined situations with four and six potential target locations. By cueing only two or three of the target locations prior to presentation of the target, we avoided the limitation identified by Tipper et al.

In the present study, we found that participants were inhibited in detecting targets at each of three previously cued locations, but only when there were four possible targets (Experiment 1). When there were six potential target locations (Experiment 3), participants were only inhibited to the one most recently cued location. What might account for this apparent discrepancy? When all potential targets in one

contiguous region are cued, it is possible to easily segregate cued from uncued regions. We believe that a spatially diffuse type of inhibition may be brought to bear in that situation. Such a situation existed in Experiment 1, when the three cued locations were adjacent to each other (i.e., there were no noncued locations interspersed among the cued locations). However, in Experiment 3, noncued potential target locations were indeed interspersed among the cued locations, thus preventing any simple segregation of the visual field into cued and uncued regions. These possibilities are further confirmed by the results of Experiment 2. In that experiment we found inhibition for the two cued locations when they were adjacent, and hence would permit diffuse inhibition over the entire cued region. However, when the two cues were on opposite sides of fixation (with intervening, noncued target locations), inhibition only occurred for the one most recently cued location. Presumably, in that case, the spatially diffuse inhibition would not have been available because the two cues were not adjacent to one another.

Finally, we note two possible alternative interpretations of our pattern of results suggested by Tipper et al. (1996). First, they correctly identify the consistent pattern in both their data and ours in which responses were slowest to the most recently cued locations (i.e., the last cued location), and less slow to locations cued earlier. Such a pattern does indeed indicate that inhibition of return consists, at least in part, of an inhibitory component that decays with time—an idea that we considered in our original article (Pratt &

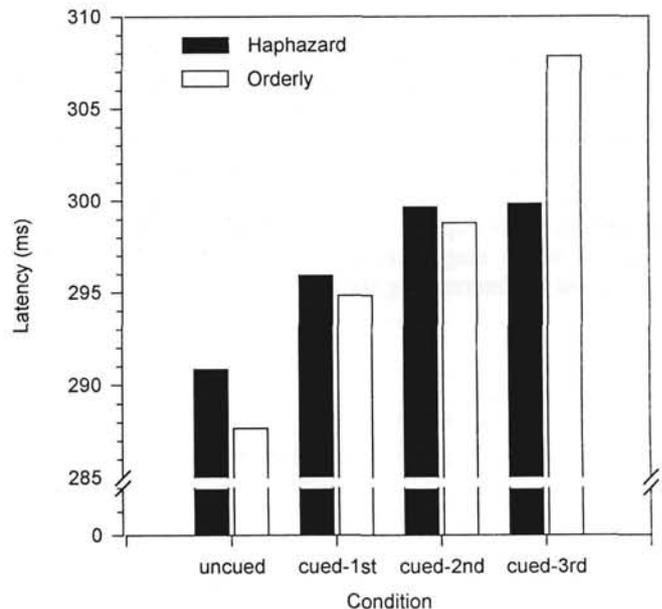


Figure 4. Mean keypress latencies from Experiment 1, separately for haphazard and orderly searches. Haphazard searches are those in which attention was cued from one side of the display to the other; orderly searches are those in which only adjacent locations were cued in succession. The important comparison is between the uncued condition and the cued-first and cued-second conditions.

Abrams, 1995). Nevertheless, the presence of such a pattern is irrelevant to the existence of the spatially diffuse inhibition that we propose here. The existence of that component is indicated by the presence of inhibition simultaneously at multiple cued locations when those locations are adjacent to one another, but the absence of such inhibition when the cued locations are not adjacent (or, more precisely, when intervening noncued locations are present). Indeed, the orderly increase in inhibition across cued locations (e.g., as seen in Figure 1 here, or Figure 2 of Tipper et al., 1996), suggests that both types of inhibition may be operating simultaneously.

The second alternative explanation suggested by Tipper et al. (1996) is that the stimuli that we used when studying nonadjacent cues are unrealistic and artificial. In particular, they suggest that the movement of attention to noncontiguous stimuli is random, chaotic, and haphazard. Presumably, it is that haphazardness that prevented us from observing inhibition of return in some of our conditions (e.g., the cued-first and cued-second conditions of Experiment 3). To investigate this possibility, we reanalyzed our results from Experiment 1, separately examining conditions in which attention was cued from one side of the display to the other (a haphazard search), and conditions in which attention was cued to adjacent locations in succession (an orderly search). Note that two thirds of the trials in our Experiment 1 (and in Tipper et al.'s experiment) involve cueing from one side of the display to the other (sometimes this transition is between the first and second cue; sometimes it is between the second and third cues). If Tipper et al. are correct, then inhibition of return should occur at the first and second cue locations only during orderly searches and not during haphazard searches. Instead, as can be seen in Figure 4, the pattern of inhibition is essentially the same for both types of trials. Thus, the Tipper et al. explanation does not appear to be correct. Instead, we believe that the presence of intervening noncued target stimuli prevents the use of a diffuse inhibition of return. The absence of such targets permits such inhibition to be applied over a broad spatial area. It is perhaps worth emphasizing that we believe that what is important in determining the presence of any spatially dif-

fuse inhibition is not so much the physical relation between cued locations, but instead, the presence or absence of intervening noncued potential targets.

Taken together, our results suggest the existence of a spatially diffuse type of inhibition that might operate on all (or at least several) potential target locations over a fairly broad spatial region. This diffuse inhibition may be distinct from (and may occur in addition to) the more finely tuned and focused type of inhibition that is typically studied in situations with small numbers of target locations. The latter type of inhibition appears to affect primarily the one most recently attended location, whereas the former may affect many recently attended locations within the inhibited region.

References

- Berlucchi, G., Tassinari, G., Marzi, C., & Di Stefano, M. (1989). Spatial distribution of the inhibitory effect of peripheral non-informative cues on simple reaction time to non-fixated visual targets. *Neuropsychologia*, *27*, 201-221.
- Hughes, H., & Zimba, L. (1985). Spatial maps of directed visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *11*, 409-430.
- Pratt, J., & Abrams, R. A. (1995). Inhibition of return to successively cued spatial locations. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 1343-1353.
- Rizzolatti, G., Riggio, L., Dascolo, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia*, *25*, 31-40.
- Tassinari, G., Aglioti, S., Chelazzi, L., Marzi, C. A., & Berlucchi, G. (1987). Distribution in the visual field of the costs of voluntarily allocated attention and of the inhibitory after-effects of covert orienting. *Neuropsychologia*, *25*, 55-71.
- Tipper, S., Weaver, B., & Watson, F. (1996). Inhibition of return to successively cued spatial locations: A commentary on Pratt and Abrams (1995). *Journal of Experimental Psychology: Human Perception and Performance*, *22*, 1289-1293.

Received May 30, 1995

Revision received September 13, 1995

Accepted December 11, 1995 ■