
Inhibition-of-Return at Multiple Locations in Visual Space

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Abstract Inhibition-of-return is thought to be a visual search phenomenon characterized by delayed responses to targets presented at recently cued or recently fixated locations. We studied this inhibition effect following the simultaneous presentation of multiple location cues. The results indicated that response inhibition can be associated with as many as four locations at the same time. This suggests that a *purely* oculomotor account of inhibition-of-return is oversimplified. In short, although oculomotor processes appear to play a role in inhibition-of-return they may not tell the whole story about how it occurs because we can only program and execute eye movements to one location at a time.

Résumé L'inhibition de retour est généralement perçue comme un phénomène de recherche visuelle caractérisé par des réactions différées aux cibles présentées à des endroits récemment indicés ou récemment fixés. Nous avons étudié cet effet d'inhibition à la suite de la présentation simultanée d'indices en divers endroits. Les résultats ont indiqué que l'inhibition de la réaction peut être associée tout au plus à quatre endroits à la fois. Il s'agirait donc d'une forme *purement* visuo-motrice d'inhibition de retour extrêmement simplifiée. En bref, bien que les processus visuo-moteurs semblent jouer un rôle dans l'inhibition en retour, ils n'en expliquent pas tout le fonctionnement car nous ne pouvons programmer ni exécuter de mouvements oculaires dans plus d'un endroit à la fois.

When people search for an object positioned among many others, eye movements appear to be biased away from previously inspected items and toward those that have not been examined yet. This inhibition-of-return effect (IOR) is thought to make visual search more efficient (Posner & Cohen, 1984). IOR is usually studied in the laboratory in one of two ways (Wright & Richard, 1997). *Saccade-induced IOR* occurs when observers make a saccadic eye movement to one location and then to another. When a

target is presented at the first fixated location, detection response times are slower than would be the case if the target was presented elsewhere (e.g., Posner, Rafal, Choate, & Vaughan, 1985). This increase in response time is usually attributed to some form of response inhibition resulting from an eye-movement biasing operation specific to a particular target location (e.g., Harman, Posner, Rothbart, & Thomas-Thrapp, 1994; Rafal, Egly, & Rhodes, 1994). *Stimulus-induced IOR* can occur when an abrupt-onset visual stimulus (usually a location cue) appears at a particular location and then a short time later (167 to 3000 ms or more; see Wright & Richard, 1997) a target is presented there (e.g., Posner & Cohen, 1984). As with *saccade-induced IOR*, detection response times are slower than would be the case if the target were presented elsewhere.

The study we describe was conducted to test the notion that *stimulus-induced IOR* can be associated with more than one location at a time. The results of previous investigations of IOR involving multiple location cues are equivocal. One study yielded magnitudes of response-time inhibition produced by a single cue and by the simultaneous presentation of two cues that were not significantly different (Posner & Cohen, 1984). In other words, following the presentation of the double cue, response inhibition appeared to be associated with both locations at the same time and to roughly the same extent. In a similar study, however, the magnitude of double-cue inhibition was roughly half that of single-cue inhibition (Maylor, 1985). The latter finding suggests that, on any given double-cue trial, only one of the two simultaneously cued locations was actually inhibited. More specifically, the difference between *single-* and *double-cue inhibition magnitudes* indicates that, averaged over trials, targets presented at one of these two locations were inhibited roughly half the time. There is also evidence that when multiple cues are presented *sequentially*, inhibition appears to occur only at the most recently cued location (Pratt & Abrams, in press). In summary, there is currently no consensus among vision researchers about IOR at multiple locations.

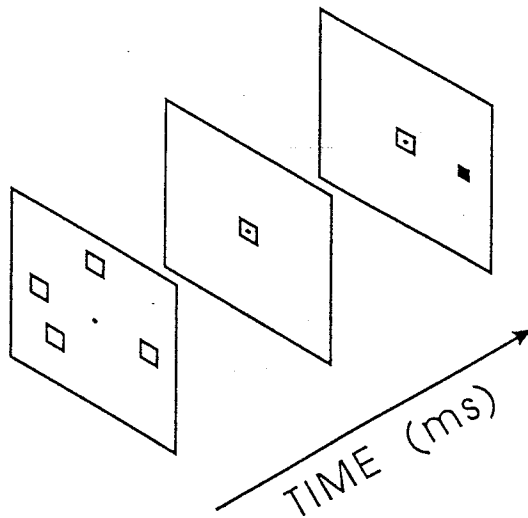


Figure 1. Example of the stimulus displays used in the experiment. In this case, four locations are simultaneously cued, the central distractor is presented, and then the target appears at a cued location.

We argue, however, that multiple-location inhibition is a robust phenomenon. In particular, like Posner and Cohen (1984), we conducted a simultaneous "single-cue versus double-cue" experiment and found response-time inhibition in both conditions (Wright & Richard, 1993). This is consistent with other data indicating that when multiple abrupt-onset location cues are presented simultaneously, visual processing (and, we argue, perceptual sensitivity change) occurs at more than one location at the same time (e.g., Wright, 1994; Wright, Richard, & McDonald, 1995). Moreover, when visual attention is actively engaged and therefore thought to be highly resistant to irrelevant stimulus onsets, there still appears to be a special treatment of up to four abrupt-onset cued locations. Yantis and his colleagues (e.g., Yantis, 1997; Yantis & Johnson, 1990; Yantis & Jones, 1991) refer to this special treatment in the engaged state as attentional priority. In other words, an initial state of sensory processing of multiple abrupt-onset stimuli appears to influence subsequent responses to these stimuli (cf. Müller & Humphreys, 1991). These findings suggest that early visual processing carried out when visual search tasks are performed is not constrained to one location at a time and that the notion of multiple-location inhibition warrants further examination. We conducted the current study to determine whether multiple IOR would occur following the simultaneous presentation of up to four abrupt-onset location cues.

METHOD

Subjects

Twenty-two Simon Fraser University students with

normal or corrected-to-normal vision took part in the experiment.

Stimulus displays

Subjects viewed stimuli displayed 60 cm away on a black (unlit) NEC Multisync computer screen. Experimental control, timing, and data collection were carried out with a 486-based computer interfaced to a response button. Location cues and targets were presented at eight possible positions in a circular array with a radius of 7.6° (see Figure 1). The cues were square ($1.9 \times 1.9^\circ$) white outline boxes separated by 5.7° , and the target was a filled ($0.95 \times 0.95^\circ$) white square. Subjects fixated on a small ($0.4 \times 0.4^\circ$) white cross that was visible in the centre of the display throughout the experiment, and pressed the response button as quickly as possible after detecting the onset of the target for which they were searching. Eye movements were not monitored because we expected IOR to occur at as many as four locations at the same time. This result could not be attributable to eye movement preparation and execution, given their serial nature (i.e., an observer cannot make eye movements to two or more destinations at the same time).

Procedure

One, two, three, or four cues were presented simultaneously at randomly selected locations within the array of cue/target positions. After a delay of 200 ms, the cue(s) disappeared and a white outline box with the same size and shape was presented at the centre location for 200 ms (a distractor stimulus). Then the target was presented at a previously cued location, an uncued location, or the location of the central distractor. This 400 ms cue-target-onset-asynchrony (CTOA) is the delay traditionally used to study IOR (e.g., Posner & Cohen, 1984) and was long enough to alleviate concerns about response-time inhibition being due to visual masking of the target by the cue. The target remained visible until a response was made, and there was a 1000 ms delay between trials. One hundred and twenty trials of each type listed in Table 1 were presented in a completely random order. Over the course of a one-hour testing session, there were 30 practice trials and 1440 data trials. As well, 480 catch trials with a 1500 ms CTOA were randomly interspersed among the data trials to reduce the frequency of response-anticipation errors.

RESULTS

A 3×4 repeated measures analysis of variance (ANOVA) was carried out on the mean response times of each subject as a function of Target Location (cued, uncued, or central distractor) and Cue Number (1, 2, 3, or 4). All response times less than 100 ms or greater than 1000 ms and all response times three standard deviations greater than or

TABLE 1

Mean detection response times (in milliseconds) for targets presented at cued, uncued, and central distractor locations. Standard errors are presented in parentheses and percentages of trials removed as outliers are shown in square brackets.

Number of Simultaneous Cues	Target Location		
	Cued	Uncued	Centre
One	331 (9.4) [2.2]	316 (10.0) [2.0]	294 (9.0) [2.2]
Two	332 (10.5) [2.4]	314 (10.3) [2.4]	291 (9.0) [2.4]
Three	330 (10.4) [2.4]	316 (9.7) [2.4]	288 (9.7) [2.4]
Four	329 (10.5) [2.5]	310 (10.2) [3.4]	287 (10.1) [2.8]

less than the mean response time for a particular condition were removed as outliers prior to the analysis.

The manipulation of Target Location, $F(2,42) = 52.6$, $MS_e = 704.5$, $p < .0001$, had a significant effect on response times, but Cue Number, $F(3,63) = 2.7$, $MS_e = 90.1$, $p > .05$, and the interaction of these two factors did not, $F(6,126) = 0.86$, $MS_e = 73.2$, $p > .05$. As indicated by the nonsignificant interaction, IOR was not affected by Cue Number. Following the convention in the literature, we determined IOR by subtracting mean response times for target detection at cued locations from mean response times for target detection at uncued locations (see Table 1). Paired comparisons of means using *t*-tests indicated that the mean response times for targets presented at single-cue ($t(21) = 5.08$, $p < .001$), double-cue ($t(21) = 5.14$, $p < .001$), triple-cue ($t(21) = 3.51$, $p < .002$), and quadruple-cue ($t(21) = 7.72$, $p < .001$) locations were significantly slower than those for targets presented at uncued locations. Thus, as seen in Figure 2, IOR occurred with equal magnitude at up to four locations at the same time.¹

DISCUSSION

The data are consistent with previous reports that single-cue and multiple-cue inhibition can occur with roughly the same magnitude (e.g., Posner & Cohen, 1984; Wright & Richard, 1993, 1994). This visual processing at more than one location following the presentation of simulta-

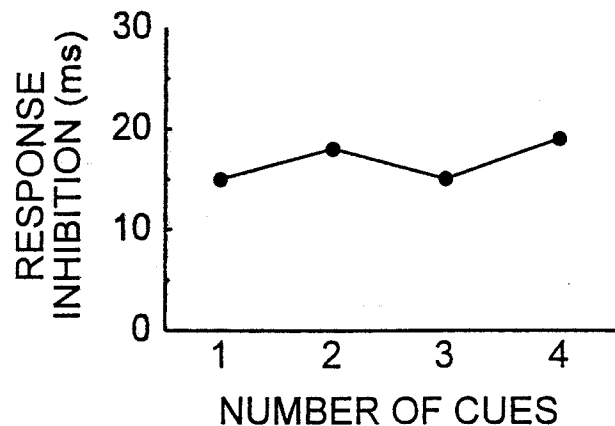


Figure 2. Response-time inhibition was determined by subtracting the mean response time for targets presented at cued locations from that for targets presented at uncued locations. Cue number refers to the number of cues presented at the same time.

neous multiple cues may reflect the visual system's capacity to keep track of several locations at the same time (cf. Pylyshyn, 1994). It also raises questions about why multiple sequential cue presentation does not appear to yield response-time inhibition for targets presented at locations other than the one most recently cued (Pratt & Abrams, in press; Wright & Richard, 1994). We suggest that a cost may be associated with processing successively cued locations that reduces inhibition magnitude at already processed or indexed locations, and that this cost, if combined with a long delay between sequential cues and target onsets, can be sufficient to attenuate inhibition at all but the most recently cued location.

The current results are inconsistent with proposals that IOR is solely due to inhibited oculomotor programming (e.g., Tassinari, Biscaldi, Marzi, & Berlucchi, 1989) because eye movements can be programmed and executed to only one location at a time. Thus, although eye movement preparation clearly plays a role in saccade-induced IOR (Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal et al., 1994), stimulus-induced IOR is not solely an oculomotor phenomenon (see also, Abrams & Dobkin, 1994). We suggest instead that, during its initial stages, IOR is mediated by an early stage of visual processing that encodes or indexes the locations of objects selected for further analysis (Wright, 1994). Thus, when searching for a particular object positioned among many others, indexing may guide the selection of object locations by marking those that have already been inspected. If the target should appear at a marked location, the response-time delay could be due to that location being designated as a low-priority region of the search set (cf. Treisman, 1997; Treisman & Sato, 1990). If it is assumed that such indexes can remain

¹ To test the robustness of the multiple IOR finding, we repeated the experiment with 10 highly practiced subjects and a 200 ms CTOA. The identical pattern of results was obtained. This is consistent with a previous finding that, with practice, subjects are able to show IOR at increasingly shorter CTOAs (Richard, Wright, & McDonald, 1994).

allocated to moving objects (cf. Pylyshyn & Storm, 1988, for a description of dynamic spatial indexes), then this proposal also accounts for both location-based and object-based IOR (Tipper, Driver, & Weaver, 1991; Tipper & Weaver, 1997). Additional research on the occurrence of the inhibition effect following multiple cueing is warranted to determine the nature of the visual operations involved and the role that they play in guiding eye movements during search.

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