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Location cue validity affects inhibition of return of visual processing

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Abstract

Inhibition-of-return is the process by which visual search for an object positioned among others is biased toward novel rather than previously inspected items. It is thought to occur automatically and to increase search efficiency. We examined this phenomenon by studying the facilitative and inhibitory effects of location cueing on target-detection response times in a search task. The results indicated that facilitation was a reflexive consequence of cueing whereas inhibition appeared to depend on cue informativeness. More specifically, the inhibition-of-return effect occurred only when the cue provided no information about the impending target's location. We suggest that the results are consistent with the notion of two levels of visual processing. The first involves rapid and reflexive operations that underlie the facilitative effects of location cueing on target detection. The second involves a rapid but goal-driven inhibition procedure that the perceiver can invoke if doing so will enhance visual search performance.

Keywords: Attention; Cue; Facilitation; Inhibition; Inhibition of return

1. Introduction

One of the consequences of visually searching a scene is an effect called inhibition-of-return (IOR). This is said to occur when there is a delay in responding to targets presented at recently fixated or cued locations. The effect is typically obtained in the laboratory in one of two ways (Wright & Richard, 1998). Saccade-induced IOR occurs when observers are required to make a saccadic eye movement to one location and then to another, and then the search target is presented at the first of these fixated locations (e.g. Posner, Rafal, Choate & Vaughan, 1985). Stimulus-induced IOR occurs when a location cue is presented somewhere and then the search target is presented there 300–3000 ms after cue onset (e.g. Posner & Cohen, 1984).[1] Posner and his colleagues (e.g. Posner & Cohen, 1984; Posner et al., 1985; Clohessy, Posner, Rothbart & Vecera, 1991; Harman, Posner, Rothbart & Thomas-Thrapp, 1994) proposed that IOR makes visual search more efficient by biasing it toward novel as opposed to previously inspected locations.

IOR does not appear to be *deliberately* strategic (e.g. Posner & Cohen, 1984). Instead, the inhibitory effects of location cueing on responses to targets seem to occur as an automatic consequence of cue onset just as facilitative effects of cueing appear to occur automatically (e.g. Jonides, 1981; Weichselgartner & Sperling, 1987; Kröse & Julesz, 1989; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Yantis & Jonides, 1990).[2] In particular, Posner and Cohen (1984) de-

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[1] In the absence of accompanying saccadic eye movement preparation, stimulus-induced IOR only occurs following the presentation of direct cues and not following the presentation of symbolic cues (e.g. Posner et al., 1985; Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Egly, & Rhodes, 1994). Direct cues (e.g. a bar-marker or outline box) are sometimes called peripheral, pull, or stimulus cues. They are usually presented at or near a target location. In contrast, symbolic cues (e.g. a digit or arrow) are usually presented in the center of a stimulus display and are used to voluntarily aim attention shifts or eye movements to a particular location.

[2] Facilitative and inhibitory effects of direct cueing at a particular location do not appear to occur, however, when attention is actively engaged elsewhere (e.g. Maylor, 1985; Yantis & Jonides, 1990; Folk, Remington & Johnston, 1992; Yantis, 1998). Therefore, the reflexive effect of direct cueing should be qualified — this property appears to hold except when suppressed by attentional engagement.

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scribed the effects of direct cueing as involving the simultaneous buildup of activation of facilitative and inhibitory components. The facilitative component was said to be dominant for the first 200 ms following cue onset, and the inhibitory component was said to be dominant 300 ms after cue onset until perhaps 3000 ms or more after its onset. As a result, the presentation of a direct cue (non-symbolic cue that appears at or near a potential target location) has been thought to inhibit responses to targets presented at its location 300–3000 ms after cue onset. One implication of reflexive inhibition is that the cue's validity (reliability as an indicator of target location) should not affect the occurrence of IOR. In other words, the fact that low-validity cues are not that useful should be irrelevant because the effect is reflexively elicited rather than cognitively mediated. Note, however, that location cue validity effects on IOR have yet to be tested directly. It is commonly assumed that they are negligible because inhibition will occur even when the cues do not provide information about target locations.

We questioned this assumption because there is evidence that, in some cases, direct cues continue to facilitate rather than inhibit responses to targets presented at cued locations 300 ms or more after cue onset (e.g. Cheal & Lyon, 1991). One interpretation of this finding is that when a cue is a valid indicator of target location, facilitative component activation will last 300 ms or more and continue to dominate the automatically triggered but weaker inhibitory component. Note that this implies that the perceiver has some degree of control over what is thought to be 'purely reflexive' facilitation by prolonging it for 300 ms or more, and this control is exerted on the basis of perceptions about the usefulness of the cue. A different interpretation is that while facilitation is reflexive, inhibition is not. In other words, a failure to find response inhibition for targets presented 300 ms or more after cue onset could be due to the fact that the inhibitory component is not activated in all situations. Although the latter interpretation is less common, we are sympathetic to it because, for example, inhibition magnitude appears to decrease over trials when the search target is continuously presented at the same location (Maylor & Hockey, 1987). That is, the occurrence of IOR appeared to be affected by the predictability of the impending target's location. If target-location predictability does, in fact, affect IOR, then inhibition cannot be a purely reflexive consequence of location cueing.

We carried out the current experiments to examine the relation between target-location predictability and inhibition. More specifically, we wanted to know whether or not IOR would be affected by the extent to which the perceiver was able to predict the location of the target being searched for. The experiments involved a comparison of the facilitative and inhibitory effects of cueing as a function of cue validity and the delay between cue and target onsets. When this delay was relatively short (100 ms or less), we expected that location cueing would lead to facilitation regardless of the cue's target-location predictability because previous research suggests that, at short cue-target-onset-asynchronies or CTOAs, such facilitation occurs reflexively (e.g. Jonides, 1981). On the other hand, when the delay was longer (300–400 ms), we expected that inhibition would be affected by the cue's target-location predictability. In accordance with our hypothesis that IOR is not purely reflexive, we expected that, at these longer delays, inhibition would occur following uninformative cues but not following informative cues.

2. Experiment 1

We conducted the first experiment to replicate a previous finding that location cueing effects on target-detection response times depend on CTOA (e.g. Posner & Cohen, 1984; Maylor, 1985; Possamai, 1985). We presented targets 66, 100, 200, 300, or 400 ms after the onset of *uninformative* direct cues to examine the effect of manipulating CTOA magnitude, and to verify that the previous finding would occur with the procedure used in the current experiments. Cueing was expected to facilitate detection response times when the CTOA was less than 200 ms and to inhibit response times when the CTOA was greater than 200 ms.

2.1. Method

Simon Fraser University students participated in each experiment. All subjects were unaware of its purpose and all had normal or corrected-to-normal vision. Stimuli were displayed on a black (unlit) computer screen at a distance of 100 cm. Experimental control, timing, and data collection were carried out with a microcomputer interfaced to a response button (Wright & Dawson, 1988). The vertices of the location cues remained visible throughout the experiment. Each trial began with a 500 ms delay followed by the 'filling in' of the rest of a location cue's parts 8° to the left or right of the center of the display (see Fig. 1). Cues were white ($1.14 \times 1.14°$) square outline boxes presented at potential target locations. After another delay of either 33, 50, 100, 150, or 200 ms, the cue's component lines disappeared with the exception of its vertices, and the central distractor box's component lines were filled in. Then, after a further delay of the same magnitude as that between the cue onset and center box onset, a target was presented either within the vertices at the cued location, the vertices at the uncued location on the opposite side of center, or the vertices at the center location. Thus, the CTOA was either 66, 100, 200, 300, or 400 ms. The target was a filled ($0.38 \times 0.38°$) white square. Targets were equally likely to appear at each of the three locations and trial presentation order was completely random.

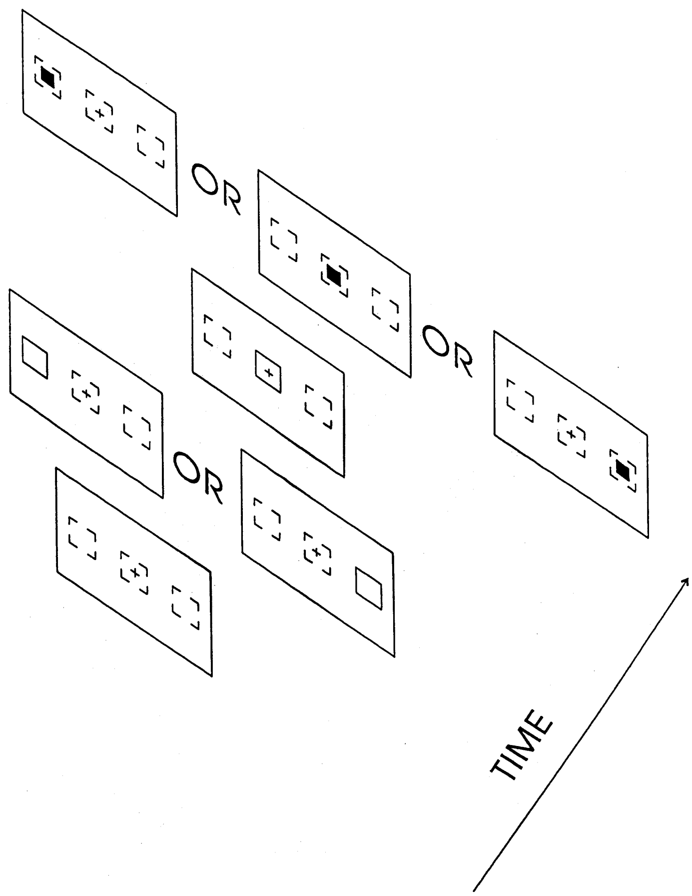

Fig. 1. Stimulus displays used in each of the experiments.

Table 1
Mean detection response times (ms) for targets presented at cued, uncued, and central distractor locations in Experiment 1 as a function of CTOA[a]

		Target location		
		Cued	Uncued	Centre
CTOA (ms)	66	337 (7.9) [1.5]	364 (10.3) [1.6]	315(8.0) [1.7]
	100	351 (7.3)[1.4]	361 (9.3) [1.5]	307 (7.2) [1.6]
	200	365 (12.6) [2.5]	367 (13.7) [2.5]	310 (11.5) [2.8]
	300	353 (7.4) [3.4]	343 (8.9) [3.9]	300 (6.1) [3.6]
	400	376 (13.3) [5.3]	356 (13.6) [4.7]	312 (12.1) [3.8]

[a] Standard error is in round brackets and percentage of trials removed as outliers is in square brackets.

Fifteen subjects were assigned to each of the five CTOA conditions. They fixated their eyes at the center of the display and were required to press a button as quickly as possible when they detected the onset of the target. In each condition, subjects received 40 practice trials followed by 1152 data trials. In addition, 576 catch trials with a 1500 ms CTOA were randomly interspersed among the other trials to reduce response anticipation errors.

2.2. Results and discussion

A 3×5 ANOVA was carried out on the mean response times of each subject for each condition with repeated measures for the Target Location factor (cued, uncued, or center) but not the CTOA factor (66, 100, 200, 300, or 400 ms). All response times less than 100 ms or greater than 1000 ms, and all response times three standard deviations greater than or less than the mean response time for a particular condition were removed as outliers prior to the analysis. As seen in Table 1, rate of outlier removal did not vary across conditions. The results indicated that changes in CTOA did not significantly affect response times ($F(4,70) = 0.43$, $MS_e = 4432.3$, $P > 0.05$). On the other hand, there were strong target location ($F(2,140)$ 373.2, $MS_e = 158.0$, $P < 0.0001$) and target location $\times$ CTOA ($F(8,140) = 10.1$, $MS_e = 158.0$, $P < 0.01$) effects. Following the convention in the literature, we determined IOR by subtracting the mean response time for target detection at cued locations from that for target detection at uncued locations (see Table 1). Paired comparisons of means (Newman–Keuls with a critical difference for 15 means at the $P < 0.05$ level ranged from 4.1 to 7.1 ms) indicated that response times for targets presented at the central distractor location were significantly faster than those for targets presented at the cued and uncued locations in all CTOA conditions. This was expected because the purpose of presenting a central distractor was to attract attention to its location immediately prior to target onset. Therefore, there should be a strong response-time facilitation effect for targets presented there. The mean response times for targets presented at the cued location were significantly slower than those for targets presented at the uncued location in the 300 and 400 ms CTOA conditions (see Fig. 2). There was no significant difference between the mean response times for targets presented at the cued and uncued locations in the 200 ms CTOA condition, however, and the mean response times for targets presented at the cued location were significantly faster than those for targets presented at the uncued location in the 66 and 100 ms CTOA conditions. Therefore, at the two longer CTOAs, location cueing led to IOR and, at the two shorter CTOAs, cueing led to response-time facilitation. This replicates a previous finding that location

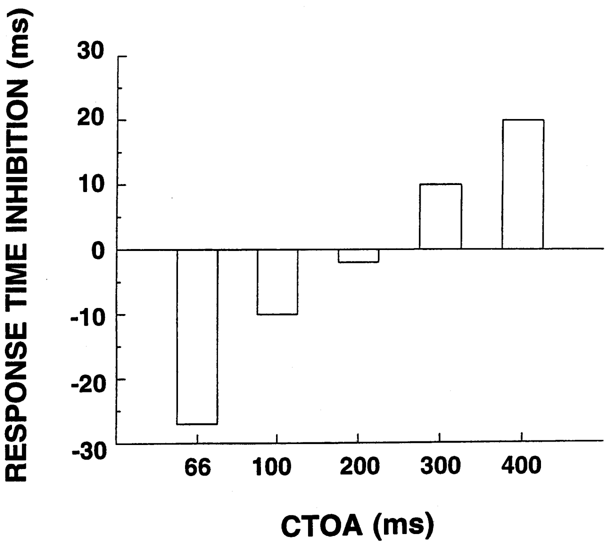

Fig. 2. Response-time inhibition as a function of CTOA in Experiment 1 was determined by subtracting the mean response time for targets presented at cued locations from that for targets presented at uncued locations. Negative inhibition values in the 66 and 100 ms conditions indicate response-time facilitation.

cue effects on detection response times can be facilitative at shorter CTOAs and inhibitory at longer CTOAs (Posner & Cohen, 1984). It is also consistent with the notion that direct cues activate a facilitative component that is dominant at CTOAs less than 200 ms and an inhibitory component that is dominant at CTOAs of 300 ms or more.

3. Experiment 2

The second experiment was conducted to determine whether or not manipulating target-location predictability would affect response-time inhibition magnitude. We used a 400 ms CTOA because this delay elicited the strongest IOR in Experiment 1. Target-location predictability was varied by manipulating cue validity. In the uninformative condition, the cues conveyed no information about the probable target location. In the high-validity condition, targets appeared at the cued location on 80% of trials. In the low-validity condition, targets appeared at the cued location on just 10% of trials. Note that, in the latter condition, because only three locations were involved, the cue was actually a reliable indicator of where the target was probably not going to appear and therefore also provided some target location information. We expected to find IOR at the cued location in the uninformative condition as in Experiment 1. On the other hand, we expected that IOR would not occur in the high-validity or low-validity conditions because, by hypothesis, target-location predictability was expected to reduce or eliminate the inhibition effect.

3.1. Method

The procedure was identical to that of Experiment 1 with the exception that only a 400 ms CTOA was used and the validity of the cues was manipulated. Fifteen subjects were tested in each of the three conditions. In the uninformative condition, as in Experiment 1, the target was equally likely to appear at the left, right, or center location regardless of the cue's location. In the high-validity condition, the target was presented at the cued location on 80% of trials, at the uncued location on the opposite side of center on 10% of trials, and at the central distractor location on 10% of trials. In the low-validity condition, the target was presented at the cued location on 10% of trials, at the uncued location on the opposite side of center on 10% of trials, and at the central distractor location on 80% of trials. In other words, subjects in the low-validity condition could ascertain that the target was probably not going to appear at the cued location and was very likely to appear in the center. Thus, the cues were uninformative about the impending target's location in one condition and informative in the other two conditions.

3.2. Results and discussion

A 3×3 ANOVA was carried out on the mean response times of each subject for each condition with repeated measures for the target location factor (cued, uncued, or center) but not for the cue validity factor. Response-time outliers were removed prior to the anal-

Table 2
Mean detection response times (ms) for targets presented at cued, uncued, and central distractor locations in Experiment 2 as a function of Cue Validity[a]

		Target location		
		Cued	Uncued	Centre
Cue validity	High	361 (11.8) [3.3]	376 (9.3) [3.5]	326 (8.4) [3.1]
	Low	403 (12.8) [6.5]	402 (16.1) [5.6]	307 (12.8) [4.8]
	Uninformative	369 (10.4) [3.4]	354 (10.6) [3.7]	315 (10.7) [3.7]

[a] Standard error is in round brackets and percentage of trials removed as outliers is in square brackets.

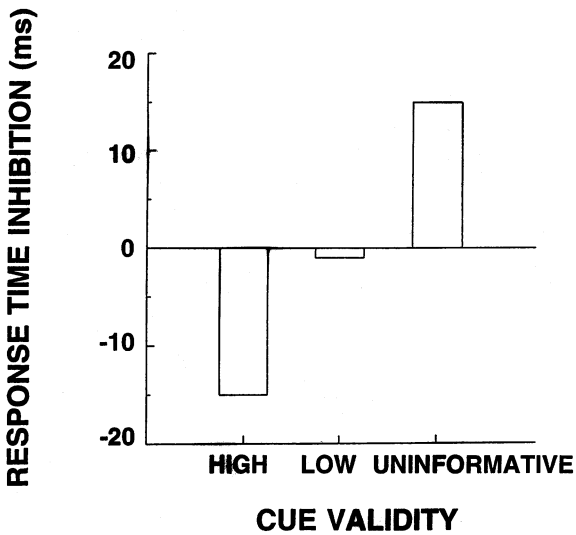

Fig. 3. Response-time inhibition as a function of cue validity in Experiment 2 was determined by subtracting the mean response time for targets presented at cued locations from that for targets presented at uncued locations. As in Fig. 2, 'negative inhibition' is equivalent to response-time facilitation.

ysis using the same technique as in Experiment 1 and, as seen in Table 2, outlier removal did not vary across conditions. The results indicated that while cue validity did not significantly affect response times ($F(2,42) = 1.29$, $MS_e = 5568$, $P > 0.05$), there were strong target location ($F(2,84) = 219.3$, $MS_e = 259$, $P < 0.0001$) and target location × cue validity ($F(4,84) = 19.9$, $MS_e = 259$, $P < 0.0001$) effects. Paired comparisons of means (Newman–Keuls with the critical difference for nine means at the $P < 0.05$ level ranged from 11.8 to 18.9 ms) indicated that response times for targets presented at the central distractor location were significantly faster than those for targets presented at the uncued location in all validity conditions (see Table 2). The mean response time for targets presented at the cued location was significantly slower than that for targets presented at the uncued location (369 vs. 354 ms) in the uninformative condition (i.e. IOR), significantly faster (361 vs. 376 ms) in the high-validity condition, and not significantly different (403 vs. 402 ms) in the low-validity condition (see Fig. 3). Therefore, IOR occurred only when the cue was uninformative and the target was equally likely to appear at any of the three locations on a given trial.

The results of this experiment indicate that IOR will not always occur if the target's location is predictable. Note, too, that cueing facilitated response times in the high-validity (high predictability) condition of the current experiment even though inhibition occurred at the cued location at the same CTOA (400 ms) with uninformative cues in Experiment 1. This can be explained in one of two ways. Either (1) inhibition does not always occur at longer CTOAs when the target location is predictable or (2) inhibition still occurs but location predictability allows the perceiver to prolong facilitation in a top-down or goal-driven manner to override it. If the latter, then presumably the perceiver realizes over trials that the cue is a useful indicator of target location and then extends the duration of the facilitative component's activation to mask the weaker inhibitory component activation. The absence of response-time inhibition in the low-validity condition, however, seems to support the first explanation. In particular, the absence of IOR suggests that the perceiver realizes over trials that targets are unlikely to be presented at cued locations, and that search would be more efficient if these locations were eliminated from the search set or at least not given special (inhibitory) treatment (cf. Treisman & Sato, 1990; Treisman, 1998).

It could be suggested that the Experiment 2 results were due to subjects adopting the following attentional focusing strategy: For those trials on which the target was most likely to appear at the center location (the low-validity condition), perhaps subjects 'became aware' of the most probable target location and may have been focusing their attention there rather than at a cued peripheral location. Similarly, for those trials on which the target was most likely to appear at a cued peripheral location (the high-validity condition), perhaps subjects became aware of the most probable target location and may have been focusing their attention there rather than at the central location. Based on these premises, one might propose that the occurrence of IOR depended only on where subjects focused their attention, regardless of cue validity. Note, however, that the notions of 'informative cueing' and 'acquired knowledge of probable target location as a function of exposure to repeated trials' go hand in hand. It is unlikely that subjects were ignoring the information provided by informative cues about the impending target's probable location while at the same time actively gauging the frequency at which targets appeared at different locations in order to determine probable target location on future trials. Moreover, given that there were two possible peripheral target locations on a given trial in the high-validity condition, subjects would know where to apply the suggested focusing strategy if and only if they first processed the location information provided by the cue presented on that trial. Therefore, cue presentations in Experiment 2 clearly influenced the pattern of results, and location cue validity did affect the occurrence of IOR across conditions in that experiment.

4. Experiment 3

We conducted the third experiment to determine whether or not cue validity also affects response-time facilitation. Recall that, in Experiment 1, facilitation occurred in the 66 ms CTOA condition, but that neither facilitation nor inhibition occurred in the 200 ms CTOA condition. In the current experiment, we used the 66 and 200 ms CTOAs again, but this time we also used low-validity cueing (as opposed to uninformative cueing in Experiment 1). We wanted to determine whether facilitation would still occur with current paradigm as it had for other researchers when cue validity was low (e.g. Jonides, 1981; Kröse & Julesz, 1989) or, instead, facilitation would be attenuated as was the case with inhibition in the second experiment. It was expected that facilitation would occur in the 66 ms CTOA condition as in Experiment 1 despite low cue validity, thereby indicating that facilitative effects of location cueing are reflexive.

Table 3
Mean detection response times (ms) for targets presented at cued, uncued, and central distractor locations in Experiment 3 as a function of CTOA[a]

		Target location		
		Cued	Uncued	Centre
CTOA (ms)	66	379 (16.7) [1.9]	402 (17.9) [1.9]	321 (10.6) [1.8]
	200	382 (11.7) [2.3]	382 (16.6) [2.7]	292 (9.6) [1.6]

[a] Standard error is in round brackets and percentage of trials removed as outliers is in square brackets.

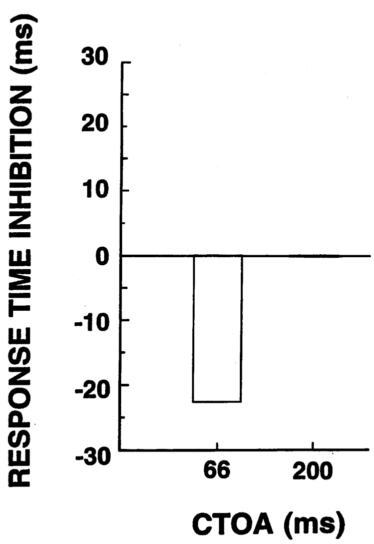

Fig. 4. Response-time inhibition as a function of CTOA in Experiment 3 was determined by subtracting the mean response time for targets presented at cued locations from that for targets presented at uncued locations. As in Fig. 2, 'negative inhibition' is equivalent to response-time facilitation. Response-time inhibition in the 200 ms was 0 ms and, therefore, no graphic bar is present.

4.1. Method

The procedure was identical to that of the previous experiment with the exception that 66 and 200 ms CTOAs were used. Also, the target was presented at the cued location on 10% of trials, at the uncued location on the opposite side of center on 10% of trials, and at the central distractor location on 80% of trials. Therefore, subjects were aware that the target rarely appeared at the cued location and usually appeared at the center location. As in the low-validity condition of Experiment 2, the cue was a reliable indicator of where the target was probably not going to appear. And therefore subjects had little incentive to use the cue to prepare a response to the impending target. Fifteen subjects participated in each CTOA condition.

4.2. Results and discussion

A 2×3 ANOVA was carried out on the mean response times of each subject for each condition with repeated measures for the target location factor (cued, uncued, or center) but not for the CTOA factor (66 or 200 ms). Response-time outliers were removed prior to the analysis using the same technique as in the previous experiments and, as before, outlier removal did not vary across conditions (see Table 3). The results indicated that manipulating CTOA had no effect on response times ($F(1,22) = 0.64$, $MS_e = 6688$, $P > 0.05$). On the other hand, there were significant target location ($F(2,44) = 163.3$, $MS_e = 319.5$, $P < 0.0001$) and target location $\times$ CTOA ($F(2,44) = 5.3$, $MS_e = 319.5$, $P < 0.01$) effects. Paired comparisons of means (Newman–Keuls with a critical difference for six means at the $P < 0.05$ level ranged from 14.8 to 21.8 ms) indicated that response times for targets presented at the central distractor location were significantly faster than those for targets presented at the uncued location in both CTOA conditions (see Table 3). The mean response time for targets presented at the cued location (379 ms) was significantly faster than that for targets presented at the uncued location (402 ms) in the 66 ms CTOA condition but not significantly different (both were 382 ms) in the 200 ms CTOA condition (see Fig. 4). Identical mean response times for targets at cued and uncued locations in the 200 ms CTOA condition accounts for the absence of a graphic bar in this condition in Fig. 4. Thus, even when the target was unlikely (10% probability) to appear at the cued location, response-time facilitation still occurred at the shorter CTOA. In other words, despite decreasing cue validity, we found the same pattern of results as in Experiment 1 at the 66 and 200 ms CTOAs.

These results indicate that the facilitative effect of stimulus cueing on detection response times will still occur at relatively short CTOAs, regardless of cue validity. On the other hand, however, the Experiment 2 data indicate that the inhibitory effect is strongly affected by cue validity at longer CTOAs (400 ms). This suggests that the facilitative effects of stimulus cueing appear to be more reflexive than the inhibitory effects, and that the perceiver is more likely to have control over the latter than the former.

5. General discussion

The experiments were conducted to examine the facilitative and inhibitory effects of location cueing on detection response times as a function of CTOA and target-location predictability. As expected, we found facilitation at short CTOAs (66 and 100 ms) regardless of cue informativeness. Conversely, we found inhibition at a longer CTOA (400 ms) only when cues were uninformative, thereby making the impending target's location unpredictable. In addition, we found facilitation at this longer CTOA when targets appeared at the cued location with a high probability (80% of trials). Our interpretation is that IOR is not a purely reflexive consequence of direct cueing. In particular, the facilitative effects of high-validity cues following a 400 ms CTOA could mean that activation of an inhibitory component is not initiated if the perceiver thinks the target will probably appear at the cued location. Furthermore, the absence of facilitative or inhibitory effects of low-validity cueing at this CTOA could mean that activation of an inhibitory component is not initiated whenever the perceiver thinks the target will probably *not* appear at the cued location. That is, given the choice, why use processing resources to inspect and keep track of a location where the target probably will not occur? If this is the case, then activation of the facilitative component may occur reflexively immediately after cue onset and last 100–200 ms if attention is not previously engaged. Activation of the inhibitory component, on the other hand, should depend on whether the perceiver needs to keep track of inspected locations in order to bias the search to other novel locations. Tipper and colleagues have also found that IOR is, to some extent, goal-driven (Tipper, Weaver & Houghton, 1994; Tipper & Weaver, 1998).

The inhibitory effect of location cueing is elicited reliably and seemingly automatically when cues are uninformative. This raises questions about how it would *not* be elicited at cued locations when target location is more predictable. We speculate that IOR is one of a class of visual processes that are rapid and relatively effortless but are also, in a limited way, under the perceiver's control. This type of processing is thought to occur, for example, whenever we perceive simple spatial relations among objects in a visual scene (e.g. Ullman, 1984). Similarly, the perceiver could invoke some form of IOR procedure whenever the location of the target being searched for is uncertain. On the other hand, when the cued location either is probably not a member of the search set or is very probably the target location, then the perceiver would be less likely to invoke the procedure, thereby making the search more efficient. The speed of the IOR procedure's execution and our lack of conscious awareness of this class of visual processing would account for why IOR sometimes seems automatic like the facilitative effects of location cueing, but is in fact not purely reflexive.

In summary, IOR appears to occur during visual search when the perceiver is unsure of the impending target's location. Future investigations of the relative automaticity of location-cue-induced response-time facilitation and inhibition may indicate that they are mediated by two different classes of visual processes — one that is reflexive and one that can be invoked if doing so will enhance visual search.

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