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ORIGINAL ARTICLE

Objects do not aid inhibition of return in crossing the vertical meridian

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Abstract Location-based cuing experiments have shown that inhibition of return (IOR) spreads beyond a cued location but appears to be confined to the cued hemifield by the vertical meridian. Previous studies have also shown that IOR can spread across objects and here we investigate whether an object can be used to mediate the spreading of IOR into the opposite hemifield. Two experiments used a rectangular object that surrounded four target locations, two to the left and right of a central fixation point. The spreading of IOR in the presence of the object was determined and compared with a condition where the object-frame was absent. Object-present and object-absent trials were either mixed within a block (Experiment 1) or divided into separate blocks (Experiment 2). Both experiments revealed robust inhibition in the cued but not the uncued hemifield, further demonstrating the hemifield-based spreading of IOR.

Introduction

Attentional cuing is known to lead to a brief period of facilitation during which the detection of a target is enhanced at the cued location. When the delay between cue and target is sufficiently large (>300 ms), however, target detection is slowed. This inhibitory aftereffect has been termed inhibition of return (IOR, Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985), denoting the fact that attention has to be disengaged from the cued location for such inhibition to occur. As such, IOR is seen as a mechanism that helps bias attention away from already attended locations toward novelty.

An important question pertains to the spatial distribution of IOR: is IOR confined to the very location where the cue occurred or does it spread to adjacent areas? Clearly, a novelty-bias would be most profitable if IOR spread beyond the cued location because locations in the vicinity of the cue often receive some covert attention.

One of the first studies to address this question was conducted by Maylor and Hockey (1985) who presented seven vertically aligned light-emitting diodes (LEDs) at either side of a central fixation cross. After one of the peripheral LEDs flashed briefly (constituting the cue), the target could occur at any of the 14 possible locations (including the cued one). Maylor and Hockey found that IOR spread beyond the cued LED to adjacent locations, with the size of this effect decreasing with increasing distance from the cue. More interesting, IOR was absent at the side that was opposite of the cue, i.e., in the left hemifield when the cue appeared at the right side and vice versa.

Following up on those early studies, Tassinari and collaborators further established the spreading of IOR beyond the cued location (Tassinari, Agliotti, Chelazzi, Marzi, & Berlucchi, 1987; Berlucchi, Tassinari, Marzi, & Di Stefano, 1989; Tassinari & Campara, 1996). Tassinari et al., for instance, used four locations that were aligned on an imagined vertical or horizontal axis, such that cues and targets could appear either to the left/right of or below/above the mid-point. Two of those four locations occurred at either side of the fixation cross. Tassinari et al. found that IOR spread to the

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uncued location in the cued hemifield but not to the uncued hemifield in either the horizontal or vertical alignment condition. Similar results were reported by Berlucchi et al. and Tassinari & Campara. The horizontal and vertical mid-line demarcations (meridians) thus appear to segment the visual field into adjacent but distinct units that impede the spreading of IOR to the opposite side.

Some findings suggest that the meridians may not be absolute boundaries, however. Bennett and Pratt (2001), for instance, presented cues in the corners of the four quadrants and found that IOR, while spreading mainly across the cued quadrant, did not systematically discontinue at the meridians. Although "slower RTs in the cued quadrant gradually gave way to faster RTs in the opposite quadrant" (pg. 78), the transition did not occur abruptly at the meridians.

The previous studies are concerned with spatial characteristics of attention and IOR. In addition to this space-based component it has now been well-established that the allocation of attention can also be based on objects (e.g., Duncan, 1984; Zemel, Behrmann, Mozer, & Bavelier, 2002). Such object-based attention is evident, for instance, in the spreading of attention throughout an object when only one end of that object is cued. In a now classical study, Egly, Driver, and Rafal (1994) presented two objects either to the left and right or above and below a central fixation cross. When one end of an object was cued, targets at the other end were detected faster relative to an equidistant target in the uncued object. Similar findings have been obtained in other studies (e.g., Moore, Yantis, & Vaughan, 1998; Abrams & Law, 2000). The objects in those studies overlaid the vertical or horizontal meridian and the spreading of attention did not appear to be hindered by those demarcations.

While those studies were concerned with the spreading of facilitatory attention, not IOR, subsequent experiments have found that an object also provides a context for IOR to spread. Jordan and Tipper (1999), for instance, increased the stimulus onset asynchrony between cue and target and observed IOR at the uncued end of a cued object (see also Reppa & Leek, 2003). In their design, however, objects were centered in one of four quadrants and did not overlap hemifields, thus, the question of whether IOR can cross meridians was not addressed. In other studies, a placeholder-like object rotated 180° around the fixation cross, into the opposite hemifield, carrying IOR across the vertical meridian (Tipper, Driver, & Waever, 1991; Tipper, Weaver, Jerreat, & Burrak, 1994). Importantly, in those studies IOR was tagged to the object and was "pulled" into the opposite hemifield, rather than spreading there in the absence of an exogenous cue.

The current study will try to close this gap by asking whether the use of objects provides a context for IOR to spread across meridians. Similar to studies of facilitatory attention, we expected that the object in the current experiment provides a context that guides and channels IOR within the boundaries of this object and allows it to spread to the other end, even if that end lies in the opposite hemifield. IOR would thus be expected to cross the meridian when the target locations are surrounded by a connecting object, but not when there is no such connecting frame. At least one earlier study suggests that such a spreading of IOR may occur. Leek, Reppa, and Tipper (2003) presented two L-shaped segments in a diagonal orientation, above and below the fixated cross. The shapes extended in the opposite vertical or horizontal quadrant on half of the trials each, and the cuing of the middle position of the object led to IOR at the end of that object. The objects in Leek et al.'s study crossed only slightly into the opposite quadrant, however, with the dominant portion of the object being confined to a single quadrant. Moreover, the diagonal alignment of the displays in their study may have further attenuated vertical meridian effects. In the current experiments we use target locations and objects that clearly extend to an equal proportion into the left and right hemifield and investigate whether such objects can mediate IOR across the vertical meridian.

Experiment 1

In Experiment 1, two target locations, aligned on an imagined horizontal axis, appeared both to the left and right of a central fixation cross. All four locations (as well as the central fixation cross) were either surrounded by a rectangular box or appeared without any such box (henceforth referred to as closed and open trials, respectively). Based on previous experiments, we expected that IOR would radiate through the object and reach, at the very least, the other location inside the cued hemifield. Here, we examined whether the object allows IOR to spread across the vertical meridian. If an object does allow IOR to spread to the opposite hemifield, an interaction between object presence and visual hemifield would be expected.

Methods

Participants

Fifteen undergraduate students from the University of Toronto participated in the experiment. All subjects had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. In addition, all participants gave their informed consent prior to their inclusion in the experiment.

Apparatus and procedure

The experiment was conducted on a PC computer with a VGA monitor, and a head/chin rest was used to ensure a viewing distance of 44 cm. Each subject was tested individually in a dimly lit, sound attenuated room.

The basic sequence of events is shown in Fig. 1. On *open* trials, the initial display consisted of a red central fixation point (subtending 0.2° of visual angle) on a black background, while *closed* trials used a similar fixation point but now enclosed within the outline of a white rectangle (15° long, 3.75° high). After 1,000 ms, a cue (unfilled white square; 1.35°) appeared for 100 ms at one of four locations that were 5° and 10°, to the left or right, of the fixation point. Following the offset of the cue there was a delay of 450 ms, then the fixation point briefly flickered (100 ms), followed by another delay of 450 ms. A target (filled white circle; 1.25°) then appeared at one of the four aforementioned locations. Participants were instructed to (1) keep their gaze on the fixation point, (2) ignore the cues as they did not predict the location of the upcoming target, and (3) press the spacebar as quickly as possible upon detecting a target. The target remained present until a response was recorded, and catch trials were used such that on some trials the target did not appear, and for these trials participants were instructed to withhold making a response. The intertrial interval was 1,000 ms. Errors occurred when participants' RTs were less than 100 ms or greater than 1,000 ms, or if a response was recorded on a catch trial.

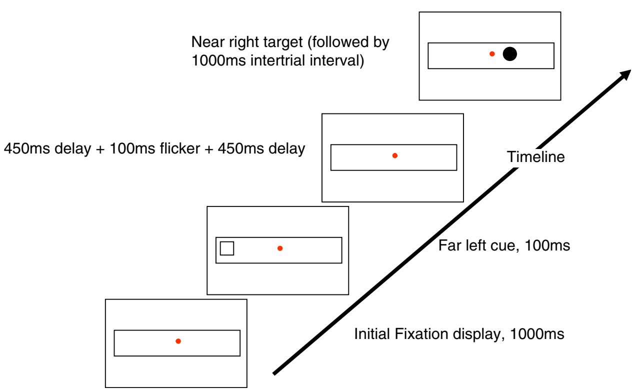

Fig. 1 The sequence of events on closed trials in both experiments. In the experiment, *white* objects where shown on a *black background*

Design

Each session consisted of 480 trials, consisting of 240 open trials and 240 closed trials, which were randomly presented in each session. In addition, within each session, cues, and targets were equally likely to appear at any of the four possible locations such that there was no relationship between cue locations and target locations. Catch trials randomly occurred on 20% of the trials. Short breaks were provided every 120 trials.

Results and discussion

The mean RTs were analyzed with a 2 (display: open or closed) × 2 (cue eccentricity: near or far) × 2 (hemifield: cued or uncued) × 2 (cue-target position: same or different) ANOVA. These means are shown in Fig. 2. The final factor, cue-target position, refers to whether the target occurred at the same eccentricity as the cue or not. For example, a trial in which the cue appeared at the far left location and the target appeared in the near right location (see Fig. 1) would be categorized as having a cue eccentricity of far, a target hemifield as uncued, and a cue-target position as different. Two main effects were found, the first being for display [$F(1,14) = 11.8$, MSe = 215, $P < 0.005$] as RTs on open display trials were 6 ms longer than on closed display trials. Replicating earlier studies, the other main effect was that of hemifield [$F(1,14) = 115$, MSe = 375, $P < 0.0001$], with RTs for targets in cued hemifields 27 ms longer than for targets in uncued hemifields. The main effects for cue eccentricity and cue-target position were not significant ($F < 1$).

Of the two interactions that reached significance, it is important to note that neither involved the factor of display. Rather, there was an interaction between cue eccentricity and cue-target position [$F(1,14) = 6.6$, MSe = 908, $P < 0.05$] and between cue eccentricity, target hemifield, and cue-target position [$F(1,14) = 4.9$, MSe = 268, $P < 0.005$]. As can be seen from Fig. 2, these interactions occurred as cued locations in cued hemifields had longer RTs than uncued locations in cued hemifields. Virtually no errors were made (<1%), precluding any further analyses.

Contrary to our expectation, the results of the first experiment suggest that IOR does not spread across hemifields. As shown in Fig. 2, the data on open trials parallel the data on closed trials to a remarkable extent. If anything, the box weakened the overall strength of IOR. As such, the results are consistent with previous studies that have identified the vertical meridian as an important demarcation for the spreading of IOR.

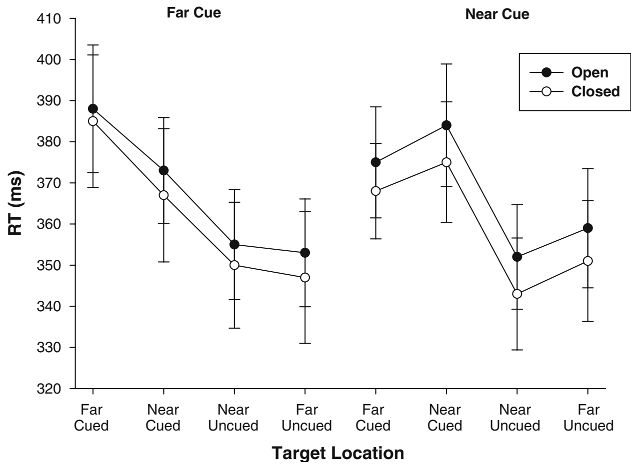

Fig. 2 Reaction times as a function of display condition, cue amplitude, hemifield, and cue-target position in Experiment 1. *Error bars* indicate the standard error of the mean

Experiment 2

The failure to find any spreading of IOR to the opposite hemifield in Experiment 1 may not necessarily be due to an absence of any effect of the object. Rather, it could be due to sequence-related interactions between object-present and object-absent trials. It has been shown, for instance, that the grouping of features into objects does not depend solely on the visual properties of a scene but also on perceptual learning from past experience. Zemel et al. (2002), for instance, demonstrated that multiple unconnected regions within a scene are perceived as belonging to the same object if previous displays have shown those regions as connected. As such, the mixed trial format of Experiment 1 may have caused perceptual learning on closed trials to carry over into open trials, with the effect that the four target regions were always perceived as belonging to a single object. This may have obscured potential differences in the spreading of IOR between open and closed trials. To avoid this confound, Experiment 1 was repeated, the critical modification being that open and closed trials were now divided into separate blocks.

Methods

Participants

Fifteen undergraduate students from the University of Toronto participated in the experiment. All subjects had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. In addition, all participants gave their informed consent prior to their inclusion in the experiment. None of the participants had been in the previous experiment.

Apparatus, procedure, and design

The apparatus was exactly the same as that used in Experiment 1. The sequence of trial events were also the same except that the open and closed trials were blocked across each session rather than randomized. Because of the number of subjects, seven participants performed the open trials first while eight participants performed the closed trials first.

Results and discussion

Block order had no main effect and did not interact with any other variable (all $F < 1$), so it was dropped from the subsequent analyses.

The mean RTs were analyzed again with a 2 (display: open or closed) × 2 (cue eccentricity: near or far) × 2 (hemifield: cued or uncued) × 2 (cue-target position: same or different) ANOVA, and these means are shown in Fig. 3. As before, main effects were found for display and hemifield. The display main effect [$F(1,14) = 4.6$, MSe = 1,832, $P < 0.05$] occurred as RTs in open display trials were 11 ms longer than on closed display trials. Once again, inhibited hemifields were found [$F(1,14) = 40.1$, MSe = 828, $P < 0.0001$], with RTs for targets in cued hemifields being 23 ms longer than for targets in uncued hemifields. The main effects for cue eccentricity and cue-target position were not significant ($F < 1$). In addition, none of the interactions reached significance ($F < 1.9$, $P > 0.18$), as the differences between cued and uncued locations within cued hemifields was smaller in the present experiment than those found in Experiment 1. Because of this, an additional 2 (display) × 2 (trial type: cued or uncued) ANOVA was conducted on the trials in which the cue and target appeared in the same hemi-field (collapsed across cue eccentricity). Here, the expected main effect of trial type was found [$F(1,14) = 5.02$, $P < 0.05$], as targets at cued locations had longer RTs than targets at uncued locations, within the cued hemifield. As before, virtually no errors were made (<1%) precluding any further analyses.

The results of Experiment 2 show that IOR was just as strong at the uncued location of the cued hemifield as it was at the cued location of that hemifield, indicating that IOR spread within the cued hemifield. Yet, the results of the second experiment replicate those of the first in that IOR did not spread to the opposite hemi-

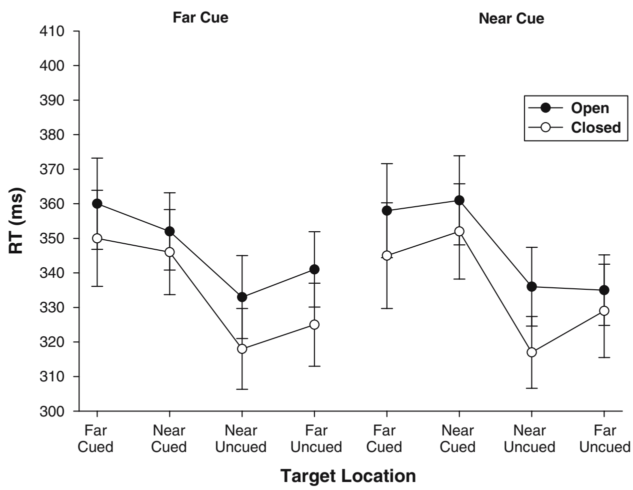

Fig. 3 Reaction times as a function of display condition, cue amplitude, hemifield, and cue-target position in Experiment 2. *Error bars* indicate the standard error of the mean

field, further demonstrating the importance of the mid-line-demarcation in limiting the spatial distribution of IOR.

General discussion

Previous studies have shown that IOR spreads beyond a cued location (Maylor & Hockey, 1985; Tassinari et al., 1987; Berlucchi, et al., 1989; Tassinari & Campara, 1996). Yet, most of those studies did not find any spreading of IOR across the vertical meridian. One potential reason for this limitation could be the specific nature of the meridian, which may function as an *absolute* boundary that prevents the interaction between hemifields. This rigorous account, however, is questioned by the fact that at least one study appears to indicate that IOR can spread into the opposite hemifield (e.g., Bennett & Pratt, 2001; see also Leek et al., 2003). A less static meridian that is not impermeable to IOR would thus be a more realistic concept; it would also be in less striking contrast to numerous other studies that have shown the spreading of *facilitatory* attention into the uncued hemifield (e.g., Egly et al., 1994; Moore, et al., 1998; Abrams & Law, 2000).

An alternative explanation for why most earlier studies failed to find any spreading of IOR beyond the cued hemifield could be the alignment of the target locations in those studies. This alignment may have emphasized the perception of the visual field in terms of two distinct hemifields. In the study by Maylor and Hockey (1985), for instance, target locations were aligned in vertical columns, which occurred 12° to the left and right of the mid-line. This alignment may have artificially increased the perception of the visual field in terms of structural segments—two distinct sides or halves—that could then attenuate the spreading of IOR into the other hemifield. A different but similarly effective bias could occur with discretely allocated, horizontally aligned targets. Here, we sought to reduce or eliminate such segmenting biases by using a box that connected the target locations of both hemifields. Both experiments indicate, however, that such a connecting box does not change the pattern of results. IOR did spread to uncued locations of the cued hemifield, as has been demonstrated in earlier studies. Importantly, however, IOR failed to spread across the meridian into the uncued hemifield.

We therefore favor another view, one that takes into account the frame of reference in which IOR occurs. If the to-be-attended area is large and targets can occur in numerous locations (as in Bennett and Pratt, 2001), a broad spreading of IOR would be highly efficient: it biases attention away from an already inspected area toward yet-to-be attended locations. The meridian may not constitute a functional barrier in this case because the probability of a target occurring in a specific location is very small. In such a case, attention does not home in on a few locations (Kramer & Hahn, 1995; Müller, Malinowski, Gruber, & Hillyard, 2003) but is distributed broadly. An inhibitory effect of the vertical meridian that reduces this distribution of IOR, and with it the efficiency of the novelty-bias, would only obstruct this effect.

If there is only a limited number of target locations, on the other hand (for example, the present study and prior work by Tassinari and colleagues), a spreading of IOR to the opposite hemifield would often mean that most, if not all, possible target locations become inhibited. The meridian may become a particularly salient demarcation in this case because it provides the most efficient division of the visual field: because of the physiological characteristics of our visual system, when a cue flashes, other location(s) in the cued hemifield are more likely to be covertly attended to than are locations at the opposite side. In order to maximize the overall grasp over a scene it would thus be efficient to subsequently attend to the previously uncued and less attended side.

Inhibition of return should thus not spread across the meridian when a limited number of target locations occur. No such limitations should apply, on the other hand, when numerous target locations occur because a spreading of IOR across the meridian would still leave enough room to prioritize other, yet unattended locations. The findings of the current and other studies are consistent with this interpretation.

We acknowledge that our conclusion of an absence of IOR in small stimulus arrays is based on negative evidence, and should therefore be subject to alternative considerations. One of them refers to the characteristics of the object: was the object in the current experiments salient enough to allow the spreading of IOR to become manifest and cross meridians? It could be possible that the object served as an ad hoc frame that narrowed and amplified attention to the area inside the object rather than function as a mediator of IOR. While such an account is possible we consider it to be unlikely. Object-present and object-absent trials were intermixed randomly in Experiment 1, and a trial-by-trial adjustment of the attended field is difficult to imagine. To the contrary, unlike other studies (e.g., Leek et al., 2003), the alignment of the four target locations along a horizontal axis in the current experiments may even enhance the perception of a grouped stimulus array, enclosed by a unifying frame, that should strengthen rather than weaken the spreading of IOR. The absence of an effect of objects on the spread of IOR is also in line with a previous study in which we investigated the effect of placeholder-style objects on the magnitude of IOR (McAuliffe, Pratt, & O'Donnell, 2001). In that study, a set of two placeholders to the left and right of the central fixation cross indicated the possible locations of upcoming cues and targets on half of the trials, with no placeholders present in the other half of the trials. The results showed that in almost all conditions the presence or absence of placeholders had little effect on the magnitude of IOR, and McAuliffe et al. took these results to argue against an object-based component of IOR that is independent of a location-based one. This interpretation may also account for the lack of IOR to spread across the meridian in the two object-conditions of the current experiment.

A second alternative consideration concerns the spreading of different types of attention through an object. Previous studies have shown that objects mediate the spreading of *facilitatory* attention across the vertical meridian (Egly et al., 1994; Avrahami, 1999). The spreading of facilitatory attention could have dominated the flow of inhibitory attention and thereby impede a measurable build-up of IOR in the opposite hemifield. This alternative seems unlikely for a couple of reasons. First, the pattern of RTs are essentially identical between open and closed conditions—if the rectangle promoted the spread of facilitation into the opposite hemifield, it is not clear what would have caused a similar effect when the rectangle was absent. Second, we have recently found that inhibition does spread through an object under appropriate conditions, even if part of that object is in the opposite hemifield (U. W. Weger, R. A. Abrams, M. B. Law, & J. Pratt, submitted). In our study, using the Egly et al. paradigm in which two objects extended either into the opposite horizontal or vertical hemifield, a central arrow cue pointed to the end of one of the objects. Target-detection at the cued segment was facilitated and this facilitation initially radiated toward the uncued segment of the object but later yielded inhibition at that location. Based on these data, we argue that the spreading of IOR is unlikely to be compromised by a more dominant facilitatory effect and that the absence of IOR in the current study is not due to a general failure of objects to mediate inhibition across the meridian. The current study extends earlier work in further demonstrating that in contrast to voluntary shifts of attention, automatic (exogenous) cues do not lead to a spread of IOR into the uncued hemifield, at least when the number of possible target locations is small.

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